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Publication Office: 20th and Northampton Sts., Easton, Pa.

Editorial Office: 845 S. Wabash Ave., Chicago, Ill.

Business Manager's Office: 654 Madison Ave., New York, N. Y.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $1.00 per year.

Non-members: Total fee $3.00, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50 per year; other countries, $4.00 per year.

Foreign Subscriptions must be accompanied by International Money Order.

Single copies: United States, $1.00 each; Foreign, $1.25 each.

Manuscript may be sent to the editor, F. W. Mohlman, 845 S. Wabash Ave., Chicago, Ill., for acceptance or rejection subject to the provisions of the Federation constitution.

Subscriptions, advertising copy, and address changes should be sent to the Business Manager's Office at Easton, Pa., or at 654 Madison Ave., New York, N. Y.

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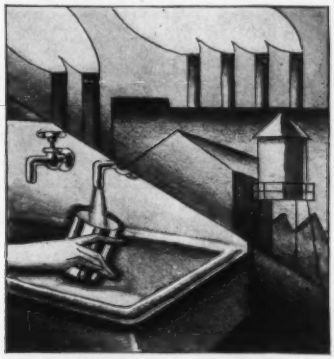

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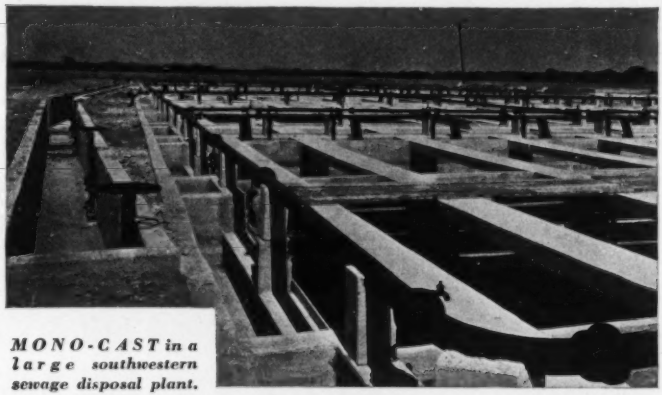

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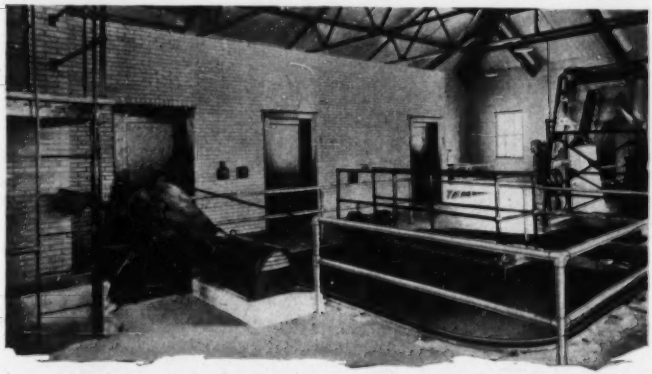

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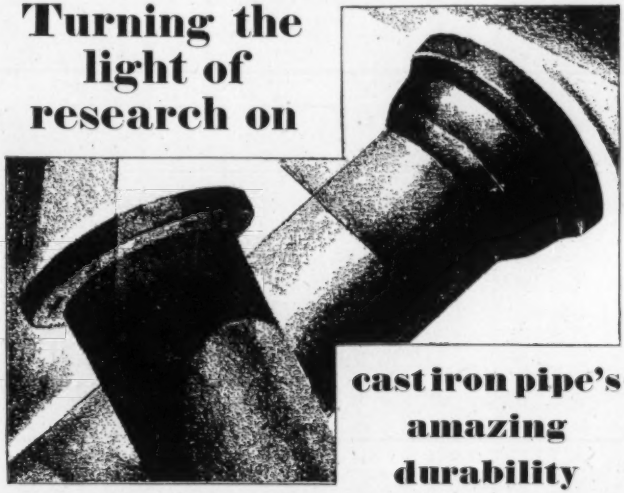

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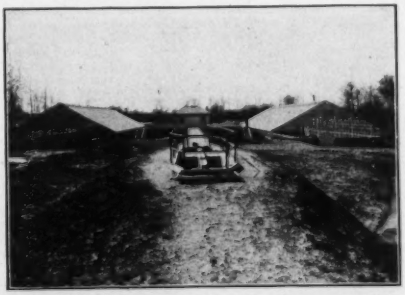

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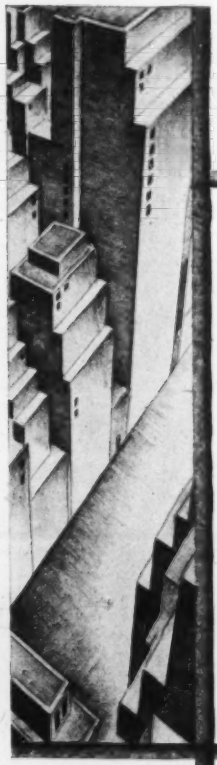

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By CARL R. MILLER

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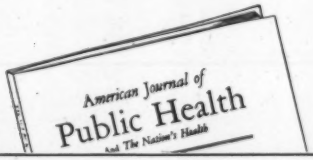

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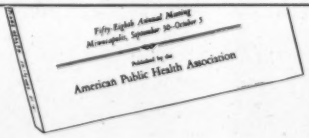

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Vol. II **April, 1930** **No. 2**

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Sewage Research

Specific Heat, Conduction and Generation of Heat during the Digestion of Sewage Sludge

By Dr. F. Sierp*

Translated by F. W. Mohlman

The decomposition of sewage sludge is due primarily to biological action, rather than to physical or chemical processes, which may often be detrimental. The optimum conditions must be provided for growth of the organisms which accomplish the decomposition, and for the proper biological, physical and chemical environment. Numerous investigations of favorable factors in digestion have demonstrated that control of the temperature is a more important factor than pH control. The optimum temperature has been demonstrated to be between 26° and 28° C. The biological processes under consideration proceed much more rapidly with increase of temperature, consequently the saving in cost of digestion capacity is quite appreciable. Temperature relations are of especial importance in comparison of two-story and separate digestion tanks. In the two-story tank the settling compartment is connected directly to the digestion compartment and transmits to the sludge compartment, through thin baffle walls, the warmth of the flowing sewage, the temperature of which, even in winter, does not fall below a definite minimum. In separate digestion tanks, with the exception of the Neustadt tank, this favorable influence is lacking. Artificial heating must therefore be provided. Various methods have been suggested for the heating of digestion tanks. Earlier procedures comprised the use of piping, which usually was attached along the walls of the tank. More recently Imhoff has used hot water for heating the auxiliary separate digestion tank in Essen-Rellinghausen. The hot water is introduced at the bottom of the tank. In diffusing upward through the tank the hot water gradually heats the sludge to the optimum temperature of 25° to 28° C. Other investigators recommend circulation of sludge and heating of sludge in a special vessel outside the digestion tank. There are three important factors to be considered in deciding which procedure is best, as follows:

1. The specific heat of the sludge.
2. The heat conductivity of the sludge.
3. The generation of heat by biological processes.

* *Chief Chemist, Ruhrverband, Kronprinzenstr. 37, Essen, Germany.*

Specific Heat

Specific heat plays a decisive rôle in the problem of heat conductivity inasmuch as substances with high specific heat require significantly greater amounts of heat for a given increase in temperature, but on the other hand are capable of slowly yielding large amounts of heat to the surrounding materials. Sewage sludge is distinguished by its high content of dissolved solids, hydrophilic colloids and gases. These substances may affect the specific heat of the sludge. If the specific heat is significantly greater than that of water, it would follow that upon cooling the sludge would give up its heat more slowly than water, upon warming a correspondingly greater amount of heat would have to be provided than if water were heated. In separate digestion tanks, for example, the sludge would lose its high summer temperature very slowly in the fall, but in the spring would require more heat and a longer time to reach the desired temperature. A determination of the specific heat by mixing sludge with water would show whether sludge has the same specific heat as water. In order to determine this, Dr. Jung and I, in the laboratory of the Ruhrverband, carried on a series of experiments, in which known weights of sludge or water were mixed with water at a known temperature. Mixtures were made in large glass vessels, which were well insulated against loss of heat, so that the temperature of the mixture would not be affected to any significant degree by transmission of heat through the walls of the vessel. Experimental conditions were the same in all tests, so that all results were affected equally by any outside influences.

Experiment I.—One liter of water at 80.5° C. was added to 8 liters of sludge at 15.2°, with thorough mixing. Under similar conditions one liter of water at 80.5° C. was added to 8 liters of water at 15.2°, with thorough mixing. The temperatures in both vessels, after mixing, were the same, namely, 22° C. The theoretical temperature should have been 22.4° C. if the sludge were of the same specific heat as water. The difference of 0.4° C. was due to the influence of outside temperature and the water equivalent of the apparatus.

Experiment II.—In the first test 800 cc. of water at 50° C. was added to 5 liters of water at 10° C.; in the second test 800 cc. of sludge at 50° C. was added to 5 liters of water at 10° C. The resulting temperature in both cases was 15.2° C., as compared with a theoretical value of 15.5° C. The difference in both cases of 0.3° C. was due to outside influences.

These tests proved that the specific heat of sludge is the same as that of water. The same results can be obtained by mixing various amounts of sludge and water.

The fact that sludge has the same specific heat as water is of special significance for the following reason. Mold production, a thermophilic

process, leads to rapid decomposition of comparatively dry sludge, with accompanying heat production within the mass of sludge, but the decomposition of wet sludge does not produce such high temperature, because the large amount of water absorbs the heat.

Conduction and Convection of Heat

Since we have shown that sludge and water have the same specific heat, it might be expected that sludge will behave like water when heated. It is fallacious, however, to advance a theory of heat balance for sludge tanks on the assumption that sludge will behave exactly like water. For such conditions the following factors are much more important with re-

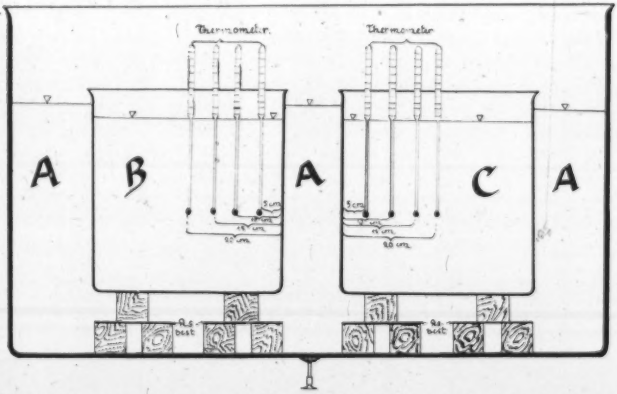

FIG. 1.—Experimental Apparatus for Determining Heat Properties of Sewage Sludge.

gard to heat transfer, namely, conduction and convection of heat and generation of heat by biological processes. These three processes are fundamentally different for sludge than for water. We devised the following experiment to prove this fact.

Experiment III.—Vessel *A* (Figure 1) was filled with water to serve as a water bath. Two metal containers, *B* and *C*, each of 60 liters' capacity and 40.5 by 40.5 cm. area, were placed in vessel *A*, resting on insulating blocks in order to prevent direct transmission of heat through the bottom of the outer vessel. Four stock thermometers, spaced 5 cm. apart, were placed in each container. Thermometer 1 was 5 cm. from the outer wall, thermometer 2—10 cm., 3—15 cm. and 4—20 cm., and all were at the same distance from the surface and bottom. Tap water was placed in con-

tainer *B* and well-digested sludge from the Imhoff tank at Essen-Rellinghausen in container *C*. By means of Bunsen burners set under vessel *A* the water was slowly heated to 20° C. The temperature was held constant until all thermometers in containers *B* and *C* read 20° C. The heating was then discontinued and the temperature of the water in vessel *A* was quickly lowered to 0° C. by means of ice. During the process of cooling of the contents of containers *B* and *C* the temperatures were recorded accurately. The results were plotted in curves.

In container *B*, which was filled with water, the temperature dropped rapidly and readings were the same for all thermometers. In container *C* the results were quite different. The temperature of the sludge decreased much more slowly than that of the water. Considerable differences were noted in thermometer readings, dependent upon the distance from the wall. For example, there was a difference of 5° C. between the temperatures indicated by thermometers 1 and 4, which were 15 cm. apart, that is, at the place where the outside temperature had greatest influence, nearest the wall, the sludge was usually only a few degrees above the temperature of the water in vessel *A*. The decrease of temperature between the water bath and the outer layer of sludge was very little. On the other hand, the sludge in the center of the containers cooled much more slowly.

This experiment showed conclusively that transfer of heat through sludge by conduction and convection is surprisingly slight as compared with transfer in water, in which the transfer is accomplished primarily by convection currents. Such currents are hardly possible in well-digested sludge, in view of the soluble, insoluble and, in particular, gaseous substances present in such material. The gas bubbles would be especially resistant to heat transfer, that is, the more bubbles the sludge contains the less heat will be conducted through it. Slight transfer of heat through the sludge is of particular importance with respect to the cooling of a separate digestion tank by radiation and other losses, since the outer layer of sludge nearest the walls of the tanks acts as insulation for prevention of heat losses. Calculations of heat losses by radiation from separate digestion tanks must therefore not be based on the average temperature of the sludge but such calculations should be corrected for the fact that the heat escapes slowly from the center of the tank because of this insulation at the walls. The actual radiation losses are accordingly much less for a tank filled with sludge than for a tank filled with water.

Heat Generated by Biological Processes

Experiment IV.—The following experiment was planned in order to show whether digesting sludge generates heat spontaneously, and, if so,

the amount of heat generated. The same apparatus was used as in Experiment III. Sludge and water were brought to 20° C. in the two vessels used in the previous experiment, and allowed to stand 2 days in the water bath. Biological action increased at this higher temperature, so that very good ebullition of gas occurred from the sludge, indicating that satisfactory digestion was proceeding. The temperature of the water in the surrounding water bath was then lowered to 0° C., whereupon the temperature of the water, and later of the sludge, slowly decreased to an average of 0° C. The contents of containers *B* and *C* were then stirred thoroughly and the water bath heated to 20° C. The bath was held at this tempera-

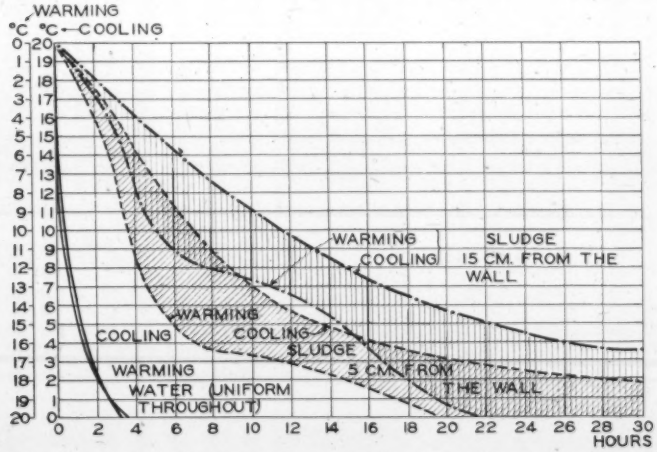

FIG. 2.—Experimental Results Showing Generation of Heat during the Digestion of Sewage Sludge.

ture until the water and sludge in the containers also reached 20° C. The temperatures recorded during this time are plotted in Figure 2. The full lines show the temperatures of the water in container *B* as indicated by the four thermometers, while the broken lines show the temperatures of the sludge as indicated on the thermometer placed 5 cm. from the wall of the container. The dot-and-dash lines show sludge temperatures 15 cm. from the walls. The areas which denote the differences between temperatures of cooling and heating for the two sludge thermometers are shaded as shown.

As in the former experiment, the temperatures of the water in container

B were similar during heating and cooling, but temperatures of sludge were different during heating and cooling. As is evident from the diagram, the temperatures of all four thermometers in the water in container *B* were the same, so that the cooling and warming curves overlap. This proves that the temperature fluctuations in the water were quickly equalized by currents, which, in this case, arose from the bottom by reason of the buoyancy of the warm water, with return downward currents. A large-scale experiment must be carried out to determine to what degree these temperatures, as recorded in vessels 40 cm. in diameter, diverge from those that would obtain in a digestion tank 8 meters in diameter and with a volume 10,000 times as large as the laboratory container.

In the sludge container the results were quite different. Although the water, when warmed, reached a temperature of 15° C. after one hour, the sludge required 6 hours 5 cm. from the wall and more than 15 hours 15 cm. from the wall. If the sludge generated no heat the warming and cooling curves should coincide as was the case with water. With the sludge, however, the cooling time was significantly longer than the warming time. The water was warmed to 20° C. in 3 hours, but the sludge, 5 cm. from the wall, required almost 20 hours, and 20 cm. from the wall, almost 22 hours. The variations on cooling from 20° to 0° are even greater. This occurred in 3 hours with water, but with sludge 5 cm. from the wall a temperature of 2° was reached in 40 hours, and 20 cm. from the wall the temperature was 3.7° C. These differences between cooling and warming must be due to generation of heat in the sludge by biological action.

In order to substantiate these results we have experimented with sludge which we sterilized with formalin, thus preventing generation of heat by biological action. About 40 l. of sludge were placed in each container. The physical structure of the sludge in container *C* was changed considerably, however, by the formalin sterilization. Likewise other means of sterilization destroyed the hydrophilic colloids, so that most of the sludge settled to the bottom. This resulted in separation of a layer of liquid around the thermometers so that temperatures recorded were identical with those recorded in the water in container *B*.

Further experiments were made in Dewar flasks one liter in capacity, in order to prevent heat conductivity and convection, but the tests led to no results of value.

The experiments described above have shown, on the one hand, that the specific heat of sludge is practically the same as that of water, but that, on the other hand, the heat conductivity of the sludge is very low and the generation of heat is large. It is desirable that these experiments be repeated at other places. With improved apparatus, in which the heat losses of the water bath can be lessened and the source of heat ac-

curately controlled, it would be possible to determine accurately the amount of heat produced by the sludge. The three factors considered herein play the most important rôle in the solution of the problem of digestion of sludge with artificial heating. Careful consideration must be given to two factors in the construction of heating devices for sludge digestion tanks. Our experimental results show the advantages of Imhoff's procedure in heating the sludge by means of hot water rather than by direct heating in outside tanks or by means of pipe coils. The hot water percolates uniformly through the sludge from the bottom of the tank to the surface, and, as shown by the tests at Essen-Rellinghausen, it distributes its heat throughout the sludge without disturbing the zone of insulating sludge just inside the walls of the tank. By reason of the generation and the slight conduction of heat, only small quantities of heat must be supplied in order to maintain satisfactory temperatures in the digestion tank. The warm water passes through the sludge, which is disturbed only by its natural agitation (gas production), so that well-digested sludge is found at the bottom of the tank near the draw-off pipe. There is a disadvantage in the use of oxygen-containing water for heating purposes, since it would delay anaerobic decomposition. In order to prevent this action it would be advisable to use supernatant sludge liquor in place of fresh water. The liquor would be heated outside the digestion tank in a special tank, or better, directly by means of pipe coils in the upper part of the digestion tank. The heated sludge liquor would be pumped to the bottom of the tank, as in Imhoff's procedure, by means of a special pump or a screw pump as used in sludge circulation, and would then rise through the tank, slowly giving up its heat to the sludge. This procedure has several advantages. Only sludge liquor, and not sludge, comes in contact with the heating tubes, thus preventing incrustation on the tubes and permitting maximum heat transfer. The digested sludge is not mixed with the undigested, so that the old, thoroughly mineralized sludge is found at the bottom of the tank and can be withdrawn therefrom. Further, the methane-producing bacterial enzymes in the sludge liquor, which are essential for good digestion, are distributed throughout the mass of sludge.

The disadvantage of earlier methods of heating of sludge, for example in auxiliary tanks, is that the sludge forms an insulating incrustation on the tubes. In order to obtain sufficient heat the tubes must not only be placed around the inner walls of the tank but also across the entire cross section.

The use of auxiliary heating tanks and also of artificial sludge circulation destroys the zone of insulating sludge which lies next to the walls of the tank and this cold sludge is then mixed with the remaining sludge, thus artificially lowering the temperature of the total volume of sludge. If

the sludge drawn from the bottom of the tank is warmed in an outside container, as in the circulation process, and then settles down through the sludge liquor, it gives up its heat to this liquor, not to mention that the sludge increases greatly in water content, which later decreases only slowly. Intensive mixing of the total contents of a tank prevents the necessary stratification of sludge according to its age and degree of digestion. It could easily happen, if the contents are mixed, that fresh, undigested sludge would be withdrawn from the bottom of the tank, while the digested sludge would remain in the tank, probably in the upper part. The latter difficulty would certainly not occur with horizontal stirring, as in the Dorr digester. The constant stirring, however, would unfortunately disturb the outer layer of insulating sludge.

Summary

1. The specific heat of sludge is practically the same as that of water.

2. Experiments indicated that transfer of heat by convection is significantly less for sludge than for water.

3. In quiescent digestion the sludge forms a protective insulating zone, which retards cooling of the tank contents.

4. A large amount of heat is generated spontaneously by biological processes in sludge undergoing digestion.

5. Artificial heating of a digestion tank may best be accomplished by means of warm water, which should be introduced at the bottom and allowed to percolate through the sludge.

6. In order to avoid the detrimental influence of oxygen-containing water, the supernatant sludge liquor may be heated by heating coils and introduced at the bottom of the tank.

7. Circulation of sludge destroys the natural zone of insulating sludge at the walls of the tank, thus artificially permitting the transfer of outside temperatures to the total contents of the tank.

Field Experiments on the Digestion of Sewage Sludge at Baltimore

BY C. E. KEEFER[1] AND W. RUDOLFS[2]

Field experiments, conducted jointly at the Baltimore sewage works by the Bureau of Sewers of Baltimore and the Department of Sewage Disposal of the New Jersey Agricultural Station, were begun June 16, 1926, and concluded Nov. 7, 1928, for the purpose of verifying on a large scale some of the results of the latter's laboratory investigations relative to the digestion of sewage sludge. The experiments indicated that unseeded sludge, the pH of which was not controlled, was only partially digested after a period of 850 days, and that by raising with lime the pH of sewage solids, introduced into a tank, from 4.9 or 5.0 to 7.2 or 7.6, very much more sludge was digested than if no adjustment of the pH were attempted.

Purpose of Experiments

The purpose of the experiments was to study the speed and nature of sludge digestion in four tanks, 12, 13, 14 and 15, all of which were operated somewhat differently. Tanks 12 and 13 received small daily additions of sludge, to which lime was added in order to keep the pH of the tank contents between 7.3 and 7.6. The only difference between these tanks was that 12 was provided with a floating cover while 13 was left open. Tank 14 was operated the same as Tank 13, except that the pH of the sludge in the former was not adjusted. Tank 15, which was also open at the top, was filled with partially digested sludge at the beginning of the experiment. This material was left undisturbed for a period of nearly $2^1/_2$ years, and the speed of digestion was observed.

All of the above tanks are of the same size and design. They are built of concrete, and are cylindrical with conical bottoms. Each tank has a diameter of 38 ft., is 15 ft. deep at the sides and $24^1/_2$ ft. deep in the center. The capacity of each tank when full is 20,600 cubic feet. The tops of the tank walls stand about 12 ft. above the ground.

Tank 12 was provided with a floating wooden cover made of 2-in. tongue-and-groove planks. Fastened to the perimeter of the cover and projecting into the sludge for a depth of 22 in. was a continuous ring of sheet metal, the purpose of which was to prevent the escape of gases generated in the sludge. There was a clearance of about 1 in. between the perimeter of the cover and the inside of the wall of the tank. An opening 6 ft. square was provided in the top of the cover, over which was secured an air-tight,

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sheet-metal enclosure. The gases from the digesting sludge passed into this enclosure, and then flowed through a meter into the atmosphere. Openings, which were normally kept gas-tight by means of gate valves, were provided in the cover to sample the sludge. The temperature in the tanks was obtained by a recording thermometer, the bulb of which was suspended 8 ft. below the wooden cover. The purpose of the cover was to prevent the escape of gas and to keep air from coming in contact with the sludge. As the other tanks had no covers, it was possible to see what effect, if any, the cover had on the digestion process.

Tank 13 was left open except for a small sheet-metal hood, which floated on the surface of the sludge. This hood was 6 ft. square, and covered less than 3 per cent of the tank surface. The function of the hood was to collect the gas given off by the sludge immediately beneath the hood so that it could be measured and analyzed.

The sludge digested during the experiment was obtained from sewage which was domestic in character and from a separate system of sewers. The sewage flowed through bar screens with $^7/_8$-in. clear openings, and thence through sedimentation tanks, which provided a 3-hr. settling period. These tanks were dewatered about once a week, and the accumulated sludge was pumped to digestion tanks. The average analyses of the sludge periodically added to the digestion tanks are given in Table I.

TABLE I

CHARACTERISTICS OF SLUDGE ADDED TO AND WITHDRAWN FROM TANKS 12, 13 AND 14

	Wet		Dry	Volatile Solids					B. O. D.
	Quantity, Cu. Ft.	Moisture, %	Solids, Cu. Ft.	Quantity, Cu. Ft.	Vol. Matter, %	pH	Acidity, p. p. m.	Alkalinity, p. p. m.	1 day 20° C.
Tank 12 (Covered) pH Controlled between 7.2 and 7.6, Oct. 1, 1926, to Sept. 30, 1927									
Sludge added	28,270	94.6	1538	1131	73.4	5.2	886	1529	...
Sludge withdrawn	28,860	94.2	1669	919	55.1	7.3	...	6590	570
Tank 13 (Uncovered) pH Controlled between 7.2 and 7.6, Oct. 1, 1926, to Sept. 30, 1927									
Sludge added	31,635	94.6.	1694	1245	73.4	5.2	906	1435	...
Sludge withdrawn	30,131	95.1	1486	802	54.0.	7.3	...	5183	551
Tank 14 (Uncovered) pH Not Controlled, Sept. 1, 1927, to Aug. 31, 1928									
Sludge added*	17,658	94.7	932	674	72.3	5.0	...	..	...
Sludge withdrawn	23,063	98.43	362	198	54.8	7.0	...	..	772

* The 5525 cu. ft. of sludge added on Nov. 15 (see Table VI) has not been included as it was digested.

The point of chief interest is that the pH of the material was about 5.0. The reason for this low reaction was that the sludge was from a week to ten days old when it was pumped into the tanks. The initial pH of the sludge as it settled from the sewage was about 6.8.

Operation of Tanks 12 and 13.—When the work was begun, Tank 12 contained 11,050 cu. ft. of sludge, the ash content of which was about 32 per cent. There was 11,250 cu. ft. of sludge in Tank 13, with approximately 36 per cent ash. The pH of the material in both of these tanks was adjusted with lime to 7.2. As the sludge at Baltimore is not considered digested unless it contains about 45 per cent or more ash, the material in neither of these tanks was ideal for the promotion of rapid digestion. The experiment, however, was started and the first undigested sludge was added to Tank 12 on June 16, 1926, and to Tank 13 on June 29, 1926. During the entire experiment the sludge was first pumped into an overhead tank shown in Figure 1. Here the volume of sludge to be introduced into the tanks was measured, samples were collected for analysis and the

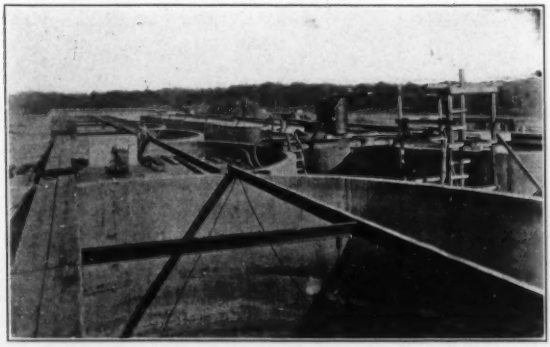

FIG. 1.—Sludge Digestion Tank Provided with Floating Wooden Cover, Baltimore Sewage Works.

lime was added. The amount of lime used varied from 85 to 155 grams per cubic foot of sludge. Although this chemical was used most of the time when raw sludge was put into the tanks, there were occasions when no lime was added, when the pH of the material in the tanks was about 7.6.

It was assumed that daily additions of undigested material could equal 2 per cent by volume of the amount of sludge in the tanks at the beginning of the experiment. During the first few weeks of the investigation, however, as indicated in Tables II and III, 2.3 per cent instead of the prescribed 2 per cent was added to Tank 12 and 2.1 per cent to Tank 13. After July 7, 1926, 2 per cent was added daily to both tanks. Since no

TABLE II

SLUDGE ADDED TO TANK 12

Date		Solids Added					
From	To	Wet Cu. Ft.	Dry Solids Cu. Ft.	%	Volatile Solids Cu. Ft.	%	Volume Added %*
1926							
June 16	July 6	4264	196.1	4.6	144.1	73.5	2.3
July 7	Aug. 6	6851	280.9	4.1	207.0	73.7	2
Sept. 2	Sept. 8	1326	51.0	3.9	38.0	74.6	2
Oct. 27	Nov. 23	5304	196.3	3.7	141.1	71.9	2
1927							
Feb. 8		2210	212.0	9.6	152.9	72.1	–
May 16	May 21	1326	86.0	6.4	61.7	71.8	2
June 13	July 19	8710	496.5	5.7	363.9	73.3	3
Aug. 23	Sept. 30	10,720	546.7	5.1	411.7	75.3	3
Oct. 1	Oct. 3	670	10.1	1.5	7.6	75.6	3

* Percentage added based on original volume of wet sludge in tank at beginning of experiment.

TABLE III

SLUDGE ADDED TO TANK 13

Date		Solids Added					
From	To	Wet Cu. Ft.	Dry Solids Cu. Ft.	%	Volatile Solids Cu. Ft.	%	Volume Added %*
1926							
June 29	July 6	1378	70.3	5.1	51.8	73.7	2.1
July 7	Sept. 7	13,275	570.8	4.3	419.5	73.5	2
Oct. 21	Nov. 26	7200	273.6	3.8	198.4	72.5	2
1927							
Feb. 8		2250	216.0	9.6	155.7	72.1	–
May 16	May 24	2025	129.6	6.4	93.1	71.8	2
June 13	July 20	9408	526.8	5.6	385.1	73.1	3
Aug. 23	Sept. 30	10,752	548.4	5.1	412.9	75.3	3
Oct. 1	Oct. 3	672	10.1	1.5	7.6	75.6	3

* Percentage added based on original volume of wet sludge in tank at beginning of experiment.

sludge was added Sunday, double the usual daily addition was pumped into the tanks Monday. After the tanks had become filled, it was frequently necessary to retain the sludge in both of them for a considerable time for the material to digest. During these periods no sludge was added to the tanks. On Feb. 8, 1927, a little over 2200 cu. ft. of sludge was put into each of Tanks 12 and 13. This was the only time during the experiment that a large quantity of sludge was added at once. After June 13, 1927, the above-mentioned daily additions of 2 per cent were increased to 3 per cent.

In order to maintain a careful control over the digestion process for the purpose of determining the effect of the lime additions on the reaction of the sludge and to trace the general trend of the digestion, samples of the sludge were obtained three times per week during the beginning of the

experiment. As the work progressed, this number was reduced to twice and later to once a week. These samples were obtained from three dif-

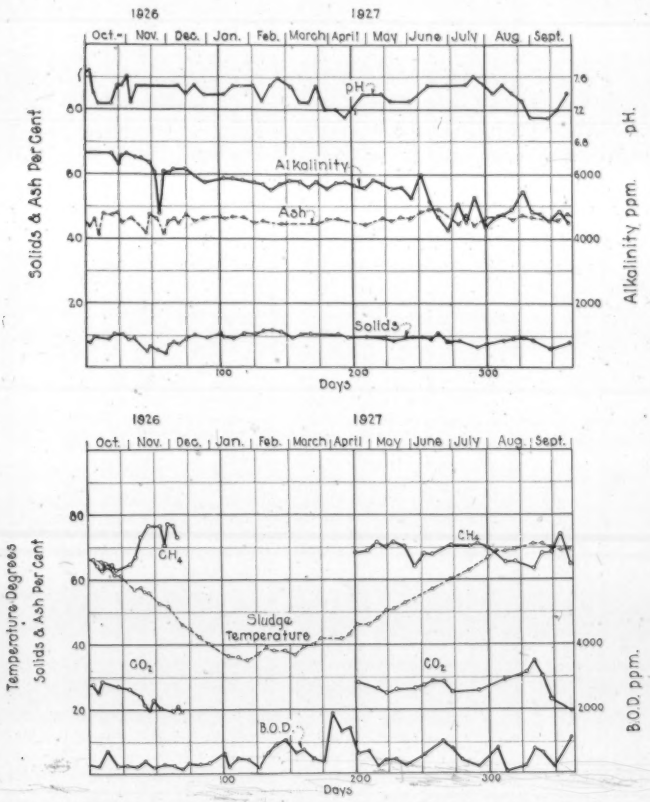

FIG. 2.—Characteristics of Sludge in Digestion Tank 12, Baltimore Sewage Works. Tank Covered. pH of Sludge Kept between 7.2 and 7.6. Sludge Added and Withdrawn at Regular Intervals.

ferent places in each tank, and were composited. Furthermore, samples of the gas were collected, and the volume collected was recorded.

Sludge and gas analyses for one year from Oct. 1, 1926, to Sept. 30, 1927, are shown in Figures 2 and 3. The results for the few months prior to Oct. 1, 1926, are not given as the sludge in Tanks 12 and 13, particularly

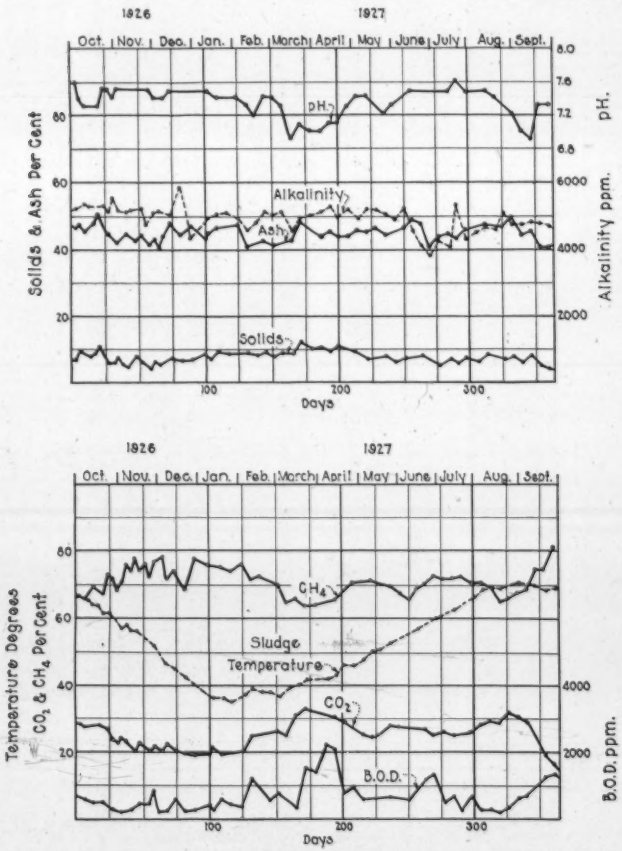

FIG. 3.—Characteristics of Sludge in Digestion Tank 13, Baltimore Sewage Works. Tank Uncovered. pH of Sludge Kept between 7.2 and 7.6. Sludge Added and Withdrawn at Regular Intervals.

the former, was not in a well-digested condition until approximately the above-mentioned date. There was little difference between the material in the two tanks. The sludge in Tank 12 had a slightly higher alkalinity and at times a little higher solid content. The percentages of ash in the sludge and methane in the gas were about the same.

TABLE IV

SLUDGE WITHDRAWN FROM TANK 12

Date	Volume, Cu. Ft.	Solids, %	Ash, %	pH
1926				
July 26	2134	7.6	38.8	7.5
Aug. 6	564	9.5	41.7	7.5
Oct. 29	2218	10.7	47.7	7.5
Nov. 12	2652	8.6	46.4	7.5
1927				
Feb. 2	4720	0.3	17.9	7.5
May 23–24	3000	1.6	37.8	...
June 10	5550	7.6	42.5	7.5
Aug. 23–Sept. 30*	10,720	4.4	44.78	7.1–7.3
Oct. 1–Oct. 3*	670	1.2	..	...

* During this period, except on Sundays and a few other days, 335 cu. ft. of sludge was withdrawn daily, which quantity was equal to the volume of sludge added daily.

TABLE V

SLUDGE WITHDRAWN FROM TANK 13

Date	Volume, Cu. Ft.	Solids, %	Ash, %	pH
1926				
Aug. 12	2503	9.4	46.0	7.5
Aug. 25	2475	9.8	48.1	7.5
Oct. 18	2150	11.3	47.2	7.3
Nov. 3	2600	7.6	45.7	7.5
Nov. 15	2475	6.1	56.5	7.5
1927				
Feb. 3	5970	0.3	44.0	7.4
May 27–28	3025	0.5	38.8	7.3
June 10	5175	6.3	42.9	7.5
Aug. 23–Sept. 30*	8736	5.6	44.4	7.0–7.3
Oct. 1–3*	672	2.6	..	...

* During this period except on Sundays and a few other days 336 cu. ft. of sludge was withdrawn daily, which quantity was equal to the volume of sludge added daily.

The floating cover placed on Tank 12 did not prove satisfactory for retaining the gas evolved from the sludge. Attempts were made to prevent the escape of gas by nailing tar-felt roofing materials to the cover, but the result was unsatisfactory. For this reason the quantities of gas

generated are not given, although they were metered. Furthermore, the volume of gas given off from Tank 13 is not reported as there was no assurance that the amount obtained from the sludge beneath the cover was similar in volume to that evolved from the sludge in the remainder of the tank.

As indicated in Tables IV and V, sludge was drawn from Tanks 12 and 13 at frequent intervals. The sludge drawn from the former tank on July 26 and Aug. 6, 1926, was not fully digested, as is apparent by the low ash content. Due to the fact that relatively more sludge than liquid was drawn so that the relation between the volumes of ripe sludge and fresh solids was changed, a quantity of liquid amounting to approximately 7700 cu. ft. was discharged from Tank 12 in February and May, 1927, and about 9000 cu. ft. from Tank 13 during the same period. If the relation between the volumes of incoming fresh solids and ripe sludge is incorrect, there is danger of upsetting the biological equilibrium. From Aug. 23 to Oct. 3, 1927, approximately 335 cu. ft. of sludge was drawn daily from each of the tanks, an amount equivalent to the volume of sludge added daily.

The sludge as removed was run on drying beds to a depth of about 12 inches. The drying period varied from 5 to 15 or 16 days, and depended to a considerable extent upon the weather. The sludge had all of the characteristics of being digested. It cracked within a few days after it was drawn from the tanks, and had an earthy odor when dry.

Operation of Tank 15.—Shortly after the digestion of daily additions of limed sludge was begun in Tanks 12 and 13, unlimed sludge was also pumped into Tank 15. This material had an ash content of about 35 per cent and a pH of about 6.1. Periodic additions of sludge were not introduced into this tank, and no attempt was made to control the pH. Sludge samples were collected fortnightly and analyzed. The results, which cover a period of 850 days, are shown in Figure 4.

In spite of the long time that the sludge remained in this tank, the digestion process was by no means complete at the end of 850 days. The ash content at the end of the period was still below 40 per cent and the pH less than 7.0. There was a gradual reduction in solids, which indicated that liquefaction took place. One additional point of interest is the temperature curve. The length of time when the digestion of sludge is intense—that is, when the temperature is above 60° F.—is only about 4½ months per year. The heating of the sludge up to this temperature throughout the year would greatly increase the tank capacity. The observations and studies made of the sludge in Tank 15 indicate that the digestion process is exceedingly slow when sludge is stored in a tank without controlling its pH or temperature or without adding sufficient quantities of ripe material for seeding purposes.

Operation of Tank 14.—After Tanks 12 and 13 had been functioning for about a year, it was felt desirable to operate another tank in the same manner as Tank 13 except that lime or other chemicals would not be added

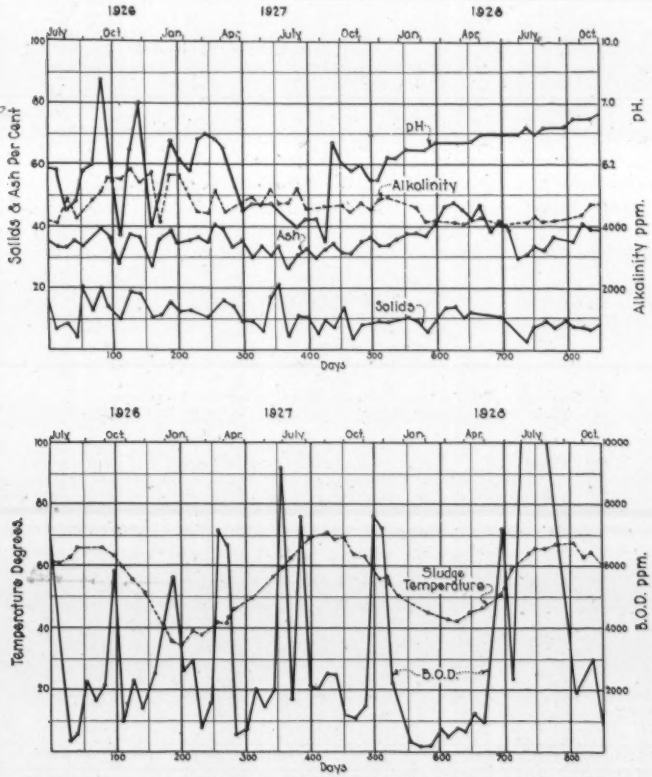

FIG. 4.—Characteristics of Sludge in Digestion Tank 15, Baltimore Sewage Works. Tank Uncovered. pH of Sludge Not Controlled. No Sludge Added or Withdrawn during Test Period.

to the daily additions of sewage solids introduced into the tank. Tank 14 was, therefore, put in service Aug. 11, 1927, at which time it contained

11,400 cu. ft. of sludge, and the work was continued until October, 1928. The quantity of sludge added daily was equal to 3 per cent of the original volume in the tank or 342 cu. ft. During the latter part of September, 1927, the quantity of digested sludge drawn amounted to 3762 cu. ft., which was equal in volume to the raw sludge added. Unfortunately, too much had been drawn, and in order to maintain the proper biological activity it was necessary to add 5525 cu. ft. of digested material on Nov. 15, 1927. From June 19 to July 20, 1928, daily additions of 426 cu. ft. of sludge were made, equivalent to 3 per cent of the dry solids in the tank April 4, 1928. Table VI gives the quantity and character of sludge added during the experiment. Data regarding the digested sludge drawn from Tank 14 are shown in Table VII. With the exception of the material (chiefly water) removed on Oct. 13 and Nov. 14, 1927, and June 12, 1928, the sludge was removed in small daily quantities, equal in volume to the daily additions of raw material.

TABLE VI

SLUDGE ADDED TO TANK 14

Date		Solids Added					
		Wet	Dry Solids		Volatile Solids		Volume
From	To	Cu. Ft.	Cu. Ft.	%	Cu. Ft.	%	Added, %
1927							
Aug. 12	Aug. 31	5376	424.7	7.9	310.9	73.2	3
Sept. 1	Sept. 9	2394	141.2	5.9	104.8	74.2	3
Sept. 21	Oct. 3	3762	90.3	2.4	68.4	75.8	3
Nov. 15*		5525	431.0	7.8	240.5	55.8	–
1928							
June 19	July 20	11,502	700.5	6.1	500.6	71.5	3

* As the tank had become partly depleted of ripe sludge due to too frequent withdrawals of material, 5525 cu. ft. of digested sludge was put into the tank to maintain good operating conditions.

TABLE VII

SLUDGE WITHDRAWN FROM TANK 14

Date	Volume, Cu. Ft.	Solids, %	Ash, %	pH
1927				
Sept. 21–Oct. 3*	3762	7.7	47.1	6.9–7.2
Oct. 13	7376	0.3	34.6	7.0
Nov. 14	5425	0.4	37.8	6.9
June 12, 1928	6500	0.4	41.1	...

* During this period except on Sundays 342 cu. ft. of sludge was withdrawn daily.

It should be noted that no raw sludge was added to the tank from July 20 to Aug. 31, 1928, and that no withdrawals were made during 1928, except that 6500 cu. ft. of water containing 0.4 per cent solids was removed June 12, 1928. The reason for not adding or withdrawing more

sludge was that digestion was exceedingly slow. As indicated in Figure 5, the pH of the sludge dropped from 6.9 to 6.1 during the latter part of June, 1928, when raw solids were being added. Furthermore, the ash

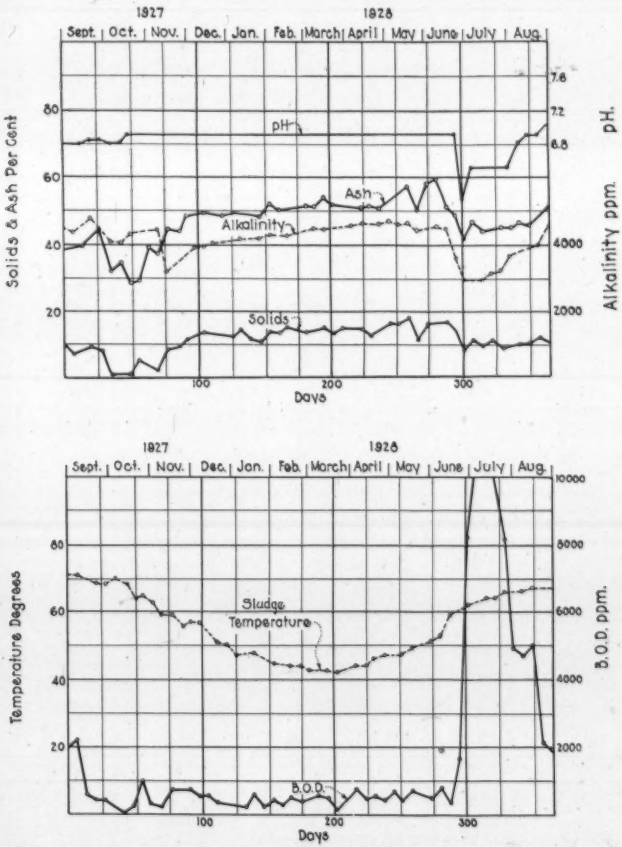

FIG. 5.—Characteristics of Sludge in Digestion Tank 14, Baltimore Sewage Works. Tank Uncovered. pH of Sludge Not Controlled. Sludge Added and Withdrawn at Regular Intervals.

content dropped from 59 to 41 per cent. It was not until after the tank had been allowed to stand idle for about a month to the end of August, that the pH was again up to 6.9 and the ash had reached 46 per cent.

Once a week samples of sludge were obtained from Tank 14 and analyzed. The observations for one year are given in Figure 5. It is of interest that the pH of the sludge was never above 6.9, although the material was well digested. In order to see if the reaction of the sludge would increase under laboratory control, a small quantity was put in a Woulff bottle, and incubated at 28° C. for 83 days. The pH during the entire period remained 6.9, and the ash content increased only from 50.1 to 52.2 per cent.

TABLE VIII

LIME ADDED, ANALYSES OF GAS PRODUCED AND ESTIMATED NUMBER OF PERSONS SERVED TANKS 12, 13 AND 14

Oct. 1, 1926 to Sept. 30, 1927

Tank	Limed Added: Total Quantity, Lbs.	Limed Added: Grams per Cu. Ft. Dry Solids	Analyses of Gas Produced: CH_4, %	Analyses of Gas Produced: CO_2, %	Analyses of Gas Produced: N_2, %	Estimated Number of Persons Served by Tank	Estimated Voume Needed for Digestion per Capita Cu. Ft.
12	6683	2059	69.8	26.0	3.7	2850	7.0
13	7379	2032	71.0	25.3	3.2	3120	6.6
14*	..	..	..	..	...	1250	15.4

* Duration of test period was from Sept. 1, 1927 to Aug. 31, 1928.

Comparison of Results

The quantities of sludge digested in Tanks 12, 13 and 14 during a 12-month period are given in Table I. Tank 12 received 1538 cu. ft. of undigested dry solids; Tank 13—1694 cu. ft., and Tank 14—932 cu. ft. By controlling the reaction of the sludge in Tank 13, over 80 per cent more material was added than in Tank 14, in which no lime was used. Furthermore, Tank 13, which was uncovered, received 10 per cent more sludge than Tank 12, which was covered. It is almost impossible to estimate even approximately the number of persons served by the three tanks since the sludge was not in the same condition in the tanks at the beginning and the end of the experiment. The following calculations, however, are of interest:

Tank 12

Dry solids in tank on Oct. 1, 1926	761 cu. ft.
Dry solids in tank on Oct. 1, 1927	378 cu. ft.
Solids necessary to add so that quantity of material in tank at beginning and end of test would be the same	383 cu. ft.

$$\text{Persons served} = \frac{1538 \text{ cu. ft. (solids added)} + 383 \text{ cu. ft.}}{0.675 \text{ cu. ft. of dry solids per capita yearly to be digested}} = 2850$$

$$\text{Volume needed for digestion} = \frac{19{,}810 \text{ cu. ft. (maximum sludge displacement)}}{2850 \text{ persons}} = 7.0 \text{ cu. ft. per capita}$$

Tank 13

Dry solids in tank on Oct. 1, 1926	1064 cu. ft.
Dry solids in tank on Oct. 1, 1927	655 cu. ft.
Solids necessary to add so that quantity of material in tank at beginning and end of test would be the same	409 cu. ft.

$$\text{Persons served} = \frac{1694 \text{ cu. ft. (solids added)} + 409 \text{ cu. ft.}}{0.675 \text{ cu. ft. of dry solids per capita yearly to be digested}} = 3120$$

$$\text{Volume needed for digestion} = \frac{20{,}503 \text{ cu. ft. (maximum sludge displacement)}}{3120 \text{ persons}} = 6.6 \text{ cu. ft. per capita}$$

Tank 14

Dry solids in tank on Sept. 1, 1927	1170 cu. ft.
Dry solids in tank on Sept. 1, 1928	1258 cu. ft.
Surplus of solids in tank at end as compared with beginning of test	88 cu. ft.

$$\text{Persons served} = \frac{932 \text{ cu. ft. (solids added)} - 88 \text{ cu. ft.}}{0.675 \text{ cu. ft. dry of solids per capita yearly to be digested}} = 1250$$

$$\text{Volume needed for digestion} = \frac{19{,}300 \text{ cu. ft. (maximum sludge displacement)}}{1250 \text{ persons}} = 15.4 \text{ cu. ft. per capita}$$

Discussion

The field experiments reported herein were originally intended to demonstrate that the rate of sludge digestion could be greatly increased by (1) proper seeding, and (2) reaction control. The usual practice at Baltimore had been to withdraw material from the digestion tanks, fill them with settled solids, withdraw the supernatant liquor from time to time, fill again with fresh solids and leave the tanks undisturbed until the mass was ready to be put on the drying beds. Instead of this procedure the experimental tanks received an amount of fairly ripe material and sludge was withdrawn at frequent intervals. In continuous operation of a separate sludge digestion tank care must be taken not to deplete the tank of ripe sludge by drawing continuously from the bottom. In practice it is well to remove as much of the supernatant liquid as possible before actual sludge drawing begins. Otherwise conditions might occur similar to those encountered during the early part of the experiment and adequately illustrated in Table IX. The fact that the experimental tanks were at times practically depleted of ripe sludge due to the withdrawal of too much digested material defeated part of the purpose of the experiment.

There is no doubt that in the removal of the ripe sludge proper seeding was made impossible for a considerable time during the experiment and that this accounts partly for the very large digestion capacities required, even when the reaction was controlled.

TABLE IX

CONDITION OF SLUDGE AT VARIOUS DEPTHS IN TANKS

Sample Depth from Top of Tank, Ft.	Tank No. 12			Tank No. 13			Tank No. 14		
	Moisture, %	Vol. Mat., %	pH	Moisture, %	Vol. Mat., %	pH, %	Moisture, %	Vol. Mat., %	pH
5	89.0	70.8	7.1	87.0	64.7	6.9	90.7	68.7	6.7
8	98.5	75.8	7.1	99.1	64.9	7.1	99.4	75.9	6.8
10	99.0	75.0	7.3	99.0	67.8	7.2	99.6	67.5	6.8
12	99.5	68.0	7.3	99.4	64.7	7.5	99.6	67.8	6.8
15	99.7	63.6	7.3	99.6	61.5	7.5	99.6	68.6	6.8
18	99.7	65.5	7.3	99.7	60.2	7.5	99.6	67.2	6.8
21	99.7	58.3	7.3	99.6	64.6	7.5	96.9	65.6	6.8

The method employed at Baltimore for settling the suspended solids in the raw sewage results in "fresh" solids which are very acid with a pH of 5.1. Large quantities of lime were therefore required to neutralize the acid material. It is also conceivable that batches of this heavily limed sludge put a temporarily excessive burden upon the biological equilibrium of the tank. Extensive laboratory studies[1] have shown that such acid materials, which have been limed and properly seeded, require much more time to digest (in addition to the time required for the acid stage) than very fresh solids, produce less gas and are biologically harder for the mixtures to handle.

On account of exposed tank walls the temperature of the sludge during the winter was as low as 35–36° F. For more than three months the temperature was 40° F. or lower (see Figures 2, 3 and 4). The average yearly temperature was 52.5° F., and the maximum was 71° F. During at least three months of the year practically no digestion took place. At temperatures below 50° F. digestion activities are extremely slow, and at this temperature it requires, under carefully controlled conditions, a year for unseeded material to digest.[2] The temperature of the material was below 50° F. for about $6^1/_2$ months.

It is to be expected that under such conditions digestion would be slow, and very large capacities would be required. Therefore any comparison with seeded mixtures subjected to average higher temperatures, as are usually obtained in Imhoff tanks, is futile. The results do show, however, the importance of temperature and the desirability, where economi-

[1] *Ann. Rept. of N. J. Sewage Expt. Sta.*, 1928–1929 (in press).

[2] *Proc. Am. Soc. Civ. Eng.*, April, 1929.

cally possible, to insulate separate digestion tanks. Even if no heating device is employed, if the tanks are properly insulated, less digestion capacities will be required. It was unfortunate that on account of the leaks in the wooden floating cover no comparisons could be made of the amounts of gas produced from the materials in the different tanks. This experience shows that floating covers made of wood are unsuited for large tanks (38 ft. in diameter). In addition to cracks through which gas escapes there is always danger of the cover warping and sagging. Only when such covers are made water- and gas-tight, and are strong enough to prevent the other possible undesirable features mentioned can comparisons with other means of gas collection and insulation be made.

No appreciable difference could be detected in the character and volume of odors coming from the four tanks. In fact the odors from these were negligible. A crust of dry scum, which tended to prevent the escape of odors, was present on the three uncovered tanks throughout the experiment.

The digested material from Tanks 12, 13 and 14, which was put on the sludge drying beds to dry, had the same general characteristics and dried in about the same period of time.

Summary

Field experiments, dealing with the effect of reaction control upon the rate of sewage sludge digestion, were conducted for two years at Baltimore. Daily charges of previously settled solids, which were acid in character, were added to uninsulated, unheated separate sludge digestion tanks. Under these conditions the results indicate that (1) by raising the pH of the settled solids from about 5.1 to about 7.3 much more material can be digested in a given period of time, and (2) sludge which is neither seeded nor the pH adjusted will not be digested after a period of 850 days.

Acknowledgments

The chemical determinations and field work were done under the direction of G. K. Armeling and E. C. Cromwell, superintendent and chemist, respectively, of the sewage plant. The sewage works is under the supervision of C. F. Goob, Chief Engineer, Department of Public Works, and Milton J. Ruark.

Observations on Two-Stage Sludge Digestion* 1928 - 29

BY A. M. BUSWELL, G. E. SYMONS AND E. L. PEARSON**

In a recent paper[1] one of us described a device for the control without chemical treatment of scum and foam during sludge digestion. Having solved these operating difficulties, we were next able to proceed with the main purpose of the investigation, namely, to study the chemical changes during two-stage sludge digestion.

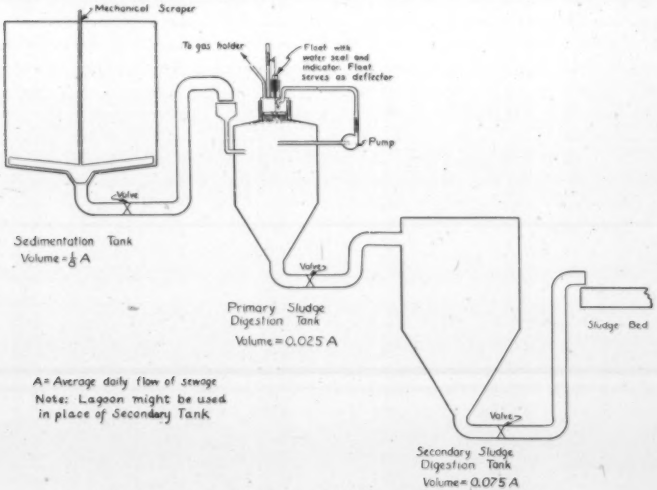

FIG. 1.—Schematic Section of Settling and Digestion Tanks.

The tanks and equipment used for the work were located in the Sewage Experiment Station of the State Water Survey and the Department of Civil Engineering of the University of Illinois. The schematic layout and details of the equipment are shown in Figure 1.

* *Presented before the Division of Water, Sewage and Sanitation Chemistry at the 78th Meeting of The American Chemical Society, Minneapolis, Minn., September 9 to 13, 1929. Published with the permission of the Editor of Industrial and Engineering Chemistry.*

** *Illinois State Water Survey, Urbana, Ill.*

[1] A. M. Buswell, "Control of Scum in Sewage Tanks," *Industrial and Engineering Chemistry*, **21**, 322, April, 1929.

The equipment actually used in this experiment had been designed for other purposes and was converted for the present use by appropriate reconstruction. The experimental equipment consisted of a Nidus sedimentation tank, which provided three hours' detention, a primary and secondary digestion tank of 2000 and 1560 gallons capacity, respectively. If we assume a connected population load of 200, the primary and secondary digestion tanks had a per capita capacity of 1.3 and 1.0 cubic feet, respectively.

This plant was operated as a two-stage digestion unit from June 15, 1928 to January 18, 1929. The primary digestion tank was filled wth raw sewage and the first sludge added June 15, 1928. Thereafter sludge was pumped from the sedimentation tanks into the primary tank three times a day, twenty-one gallons at a time, except for three weeks in September, 1928, when no sludge was added.

Six weeks elapsed before the secondary tank was put in operation. To start this secondary tank 520 gallons of digesting sludge were transferred from the primary tank to the bottom of the secondary tank, the remainder of the tank being filled with tap water. Sludge was next transferred three weeks later.

It was soon observed that relatively little gas was produced in the secondary digestion tank. Therefore the frequency with which sludge was transferred from the first to the second tank was increased until transfers were made every 5 to 8 days (see Figure 2). The amount of sludge transferred varied from 100 to 150 gallons at a time. This schedule of frequent transfers was followed from about October 1, 1928, until the end of the experiment in January, 1929.

The chemical data are given in Table I. It will be noted that this table gives the results of digestion in terms of total solids only. Analytical and sampling difficulties, which could not be detected until the end of the experiment, made it impossible to present the data in any other form. The figures for total solids, "grease," cellulose and gas produced are direct determinations. The cellulose refers to so-called alpha-cellulose (Schweitzer's reagent followed by acid precipitation), and does not include crude fiber. The figure for protein is obtained by multiplying the organic nitrogen (total nitrogen minus ammonia nitrogen) by the factor 6.25. The concentration of sulphate is calculated from figures obtained by Elder.[1] Since Elder's data were not collected for this particular investigation, the figures must be regarded as approximations. The figure for crude fibre digested is obtained by subtracting the amount of "grease," cellulose and protein digested from the total weight of gas. We justify this calculation on the basis of results of bottle experiments

[1] A. L. Elder with A. M. Buswell, "Changes of Sulphur Compounds during Sewage Treatment," *Industrial and Engineering Chemistry*, **21**, 560, June, 1929.

TABLE I

EFFECT OF TWO-STAGE DIGESTION ON SEWAGE SOLIDS

Material	Added, Lbs.	Residue, Lbs.	Digested, Lbs.	Produced, Lbs.	Liquefied, Lbs.	Digestion, Per cent	Liquefaction, Per cent
Total solids[1]	2305.0	858.8	1446.2	...	....	62.6	..
Grease[2]	747.96	72.9	675.06	...	....	90.3	..
Cellulose[3]	40.3	3.0	37.3	...	....	92.5	..
Protein[4]	308.0	112.3	195.7	...	....	63.5	..
Sulphate (SO_4)[5]	90.0	15.0	75.0	...	....	83.0	..
Crude fibre[6]	.....	...	294.0	...	....	..	..
Dehydration[7]	.....	...	169.2	...	....	..	..
Ammonia comp.	24.5	130.9	.....	106.4	....	..	..
Settling solids	2250.0	567.6	.....	...	1682.4	..	74.8

Gas produced (CH_4, CO_2, H_2)[8]

1st tank = 15,687 cubic feet = 1063.4 pounds
2nd tank = 2036 cubic feet = 138.6 pounds
Total = 17,723 cubic feet = 1202.0 pounds

[1] Includes ammonium compounds (acetate and carbonate).
[2] Petroleum ether extract.
[3] Alpha cellulose.
[4] Protein = 6.25 (total nit.-amm. nit.).
[5] Estimated from data of A. L. Elder.[1]
[6] Crude fibre = gas − (grease + cellulose + protein digested).
[7] Solids digested − (gas + sulphate) = dehydration.
[8] Includes dissolved and bicarbonate CO_2.

which have shown a very close relation between organic matter digested and gas produced. In subsequent experiments we plan to make a direct determination of this factor. The difference between the total solids digested and the sum of the "grease," cellulose, protein, sulphate and crude fiber digested has been attributed to dehydration or loss of hydrophilic properties. We have had several indications that this occurs. Experiments now in progress will furnish a check on this assumption.

The most interesting data in this table are those on gas production (see also Figure 2). These data were collected under favorable conditions and we feel satisfied that they are accurate to within one per cent. The largest error involved is the loss of gas during sampling and sludge transfer operations.

It will be observed that practically 90 per cent of the gas was produced in the first tank, although the sludge during the major part of the experiment remained in that tank for only seven or eight days. It is also interesting to note that 90 per cent of the "grease" was digested and that the

[1] A. L. Elder with A. M. Buswell, "Changes of Sulphur Compounds During Sewage Treatment," *Industrial and Engineering Chemistry*, **21**, 560, June, 1929.

weight of "grease" digested corresponded to more than 56 per cent of the gas. The gas produced was 0.39 cubic feet per capita per day from both tanks, or 0.34 cubic feet per capita per day in the primary stage. The gas produced in the primary tank was 12.3 cubic feet per pound of solids digested.

Though the major part of the digestion takes place in the primary stage, there is a further ripening in the secondary tank necessary to complete the biochemical reaction and produce an inoffensive and rapidly draining sludge.

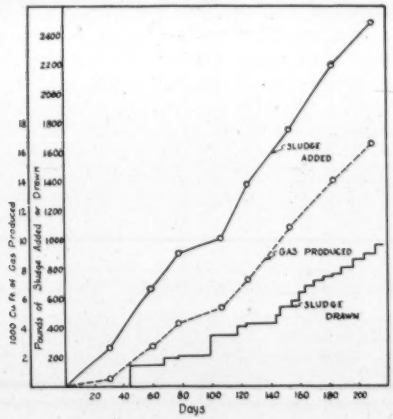

FIG. 2.—Total Sludge Added and Withdrawn and Total Gas Produced, Primary Tank.

An average of 150 analyses of the gas indicated that it consisted of 64 per cent methane, 28 per cent carbon dioxide, 3.4 per cent hydrogen, and 4.3 per cent nitrogen, with a calculated heat value of 640 B. t. u. per cubic foot.

The data suggest a somewhat clearer picture of sludge digestion than we have had heretofore. It might be pictured as follows:

There is at first a relatively rapid fermentation which results in the decomposition of the simpler compounds and the production of a large quantity of gas, including most of the hydrogen sulphide. This fermentation is apparently complete in a very few days. This observation is in accord with that of Hatfield[1] and others, who have observed that 50

[1] W. D. Hatfield, G. E. Symons and R. R. Mills, "Gases from Sewage Sludge Digestion," *Industrial and Engineering Chemistry*, **20**, 174, February, 1928.

per cent of the gas is evolved in the first 24 hours. After this fermentation has reached completion, it is still necessary to allow the sludge to undergo some sort of a ripening process. The exact nature of this is not understood but the net result is that the sludge loses its water-binding properties and can then be drained on sand beds.

The complete digestion process could best be carried out in a separate sludge digestion plant consisting of a relatively small primary tank designed to allow 6 or 8 days detention and equipped with the necessary circulating devices to prevent scum and foam formation, followed by a secondary tank or even a lagoon of sufficient size to allow for the necessary ripening of the sludge to a state where it will drain on sand beds (Figure 1). This would result in the following economies: (1) cost of cover would be reduced to approximately one-tenth; (2) since no scum is observed in the secondary stage of digestion, no special measures would have to be taken to prevent scum formation; (3) it is possible that only the primary tank would need to be heated, and (4) the secondary tank might be replaced by lagoons.

Control of Scum in Sewage Tanks.—The circulation of sludge liquor for control of scum formation in sludge digestion tanks was reported by Dr. A. M. Buswell in connection with experimental studies of separate digestion at the Illinois State Water Survey. The tank had a capacity of 1900 gallons, and was 7 ft. 8 in. in diameter by 8 ft. 6 in. deep. It was provided with a fixed cover and central gas-collecting dome 2 ft. 4 in. in diameter.

Stiff scum built up to a depth of 26 inches even though a grid, as suggested by Dr. Imhoff, was installed. A pump and piping were installed so that liquor could be pumped up at the rate of 10 gallons per minute and allowed to flow onto the scum. Ten days' circulation disintegrated the scum. Thereafter circulation for 5 to 10 minutes a day prevented further scum formation.

The effect of circulation on foaming was next tried. Vigorous foaming was induced by raising the temperature of the scum to 37° C. The pump was then started. Within 3 minutes the foam had subsided 7 inches. Thereafter routine circulation for 5 to 10 minutes a day was usually sufficient to prevent foam formation.

Dr. Hatfield installed circulation in 4 of the 18 gas collectors of a foaming Imhoff tank at Decatur. During 6 weeks' operation the foaming was so well controlled that connections were placed in all of the 108 gas collectors of the 6-tank plant.

The cost of circulation for another plant was estimated at $5 per day, compared with $100 by the use of lime.—*Ind. Eng. Chem.*, **21**, 322–323, April, 1929.

Further Studies on Thermophilic Digestion of Sewage Solids*

BY H. HEUKELEKIAN**

In a prior publication results of studies on thermophilic digestion of sewage solids were reported.[1] Briefly it was found that when fresh solids were incubated at temperatures of 45–60° C. digestion took place slowly. At these high temperatures there was a relatively prolonged period of lag in the gasification of solids seeded with ripe sludge, but once gasification started it proceeded at a very rapid rate. The total time of digestion was not less than what would be expected from the incubation of a similarly seeded mixture at 28° C. (25–30 days). However, it appeared that by using a sludge produced under thermophilic conditions for seeding purposes the preliminary period of adjustment of bacterial flora to the thermophilic conditions could be greatly curtailed. Such proved to be the case and the digestion time was reduced to 18–20 days by using thermophilic sludge. Considering, however, the high temperatures employed the results were still considered unsatisfactory from a practical standpoint. Subsequent studies were undertaken to attempt further curtailment of the digestion time, part of the results of which will be reported here.

Methods

Fresh solids were obtained in the usual manner from a sedimentation tank at Plainfield, New Jersey. These were seeded with sludge produced under thermophilic conditions in the laboratory. Mixtures were made of two parts of fresh solids to one of ripe sludge on the basis of volatile matter, except when otherwise stated. These were put into incubators and digested at 50° C. (122° F.) and compared with mixtures digested at lower temperatures. The gas evolved was measured daily and the time for complete digestion was determined from the rate of gas evolution. Solids, ash and pH values were also determined.

Results

The Effect of Reaction Adjustment in Seeded Mixtures.—The effect of reaction adjustment with lime on the thermophilic digestion of seeded mixtures was first determined. The quantities of lime added and the pH values of the initial mixtures, as well as at different intervals of digestion, are given in Table I. The pH values during the course of digestion were determined not from the samples that were used for gas measurements but from a parallel series of samples in bottles which were opened

* *Journal Series Paper, New Jersey Agricultural Experiment Station, Department of Sewage Disposal.*

** *Research Bacteriologist, Dept. Sewage Disposal.*

occasionally for the determination of pH values. The pH values of the control mixture increased from 7.4 to 7.6. The mixture which was initially

TABLE I

Days	Grams Lime Added[1] 0	2.1	3.3	6.7
		pH Values		
Initial	7.4	7.8	8.2	8.7
1	7.4	7.6	7.7	8.5
4	7.4	7.5	7.6	7.5
7	7.7	7.7	7.7	7.7
11	7.6	7.7	7.8	7.6
14	7.6	7.7	7.7	7.7
Yield of gas[2]	845	840	745	680

[1] Per liter of 3.5% fresh solids.

[2] Per gram of volatile matter in fresh solids.

adjusted to 7.8 dropped to 7.5 in 4 days and then increased to 7.7. The mixtures adjusted to 8.2 and 8.7 showed a similar tendency. Figure 1 shows the daily gas production from these mixtures. The maximum

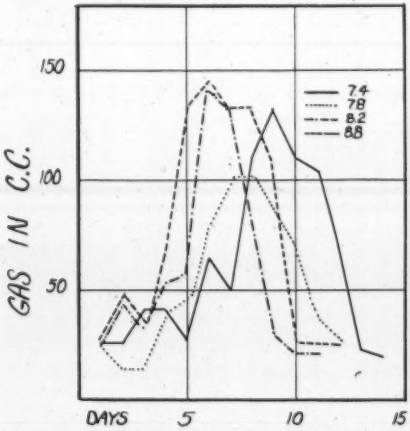

FIG. 1.—Daily Gas Production during Thermophilic Digestion of Seeded Mixtures Adjusted to Different pH Values with Lime.

gas production in the control mixture took place after 7 days and was completed in 13 days. In the mixture initially adjusted to a pH value of 7.8 maximum gas production took place after 5 days and was com-

pleted in 10 days; with an initial pH value of 8.2 maximum gas production was obtained after 4 days and was completed in 9 days; with an initial pH value of 8.7 maximum and minimum gas production occurred in 5 and 12 days, respectively. The maximum amount of gas produced in one day was somewhat lower with an initial pH adjustment to 8.7. The maximum daily rate of gas production from the other mixtures was almost 150 cc. per gram of raw volatile matter per day, which is nearly three times the rate attained under the most favorable conditions of non-thermophilic digestion. Similarly a digestion period of 10–13 days is less than half as long as has been attained under the most favorable laboratory conditions. It would appear from these results that the addition of lime even in thermophilic digestion, which is much more rapid than non-thermophilic digestion, results in a further curtailment of time. This occurs in spite of the fact that the pH value of the unadjusted mixture does not drop below 7.4. An excessive amount of lime as in the mixture adjusted to pH 8.7 is, however, not beneficial. The total yield of gas is recorded in Table I. The yield of gas for the control mixture and the one adjusted to pH 7.8 was 840 cc. per gram of raw volatile matter. The mixture adjusted to higher pH values gave a lower yield of gas.

Reduction of the Quantity of Sludge.—It was felt that since digestion was so rapid at these high temperatures it might be possible to reduce the quantity of seed material without materially affecting the time of digestion. Therefore an experiment was set up in which the amount of ripe sludge was progressively reduced, as indicated in Table II.

TABLE II

REDUCING THE QUANTITY OF SLUDGE IN THERMOPHILIC DIGESTION

	Fresh Solids[1]	Ripe Sludge[1]	Ratio	Digestion Time (Days)	Total Gas[2] (Cc.)
1	10	5	2:1	12	800
2	10	2.5	4:1	18	830
3	10	1.25	8:1	35	810
4	10	0.875	11.4:1	44	845

[1] Grams of volatile matter.

[2] Grams of raw volatile matter.

The days required for complete gasification and the total gas produced are also given in this table. The time required for complete gasification was based on maximum reduction in the rate of gas production. The table shows that decreasing the quantity of sludge increased the time of digestion. Reducing the quantity of sludge to nearly one-sixth of the original amount increased the time of digestion from 12 to 44 days. At 20° C. the digestion of even a 2:1 mixture would require nearly 40 days.

Reaction Adjustment and Reduction of the Quantity of Sludge.—It has been shown that sludge has a twofold function,[2] first, that of regu-

lating the reaction of the digesting mixture and, second, that of furnishing the proper flora to carry on the digestion. It seemed reasonable to expect that if the reaction could be regulated in some other way the quantity of sludge might be reduced without prolonging the digestion time. Of the substances in ripe sludge which might serve to regulate the reaction, ammonium bicarbonate and ammonium carbonate were selected and were supplemented with dipotassium phosphate. The reaction of the fresh solids was adjusted with lime and these alkaline salts were added to prevent the reaction from dropping. The quantities of these salts added per liter of fresh solids with 95 per cent moisture were as follows:

	Grams
Lime	3.0
Ammonium bicarbonate	2.7
Ammonium carbonate	1.4
Dipotassium phosphate	1.4

To one series only lime was added while to another lime was used in conjunction with the alkaline salts, in order to determine the relative value of lime and the alkaline salts used. All samples were seeded in the ratio of 2:1, 4:1, and 8:1 (the first figure in each case refers to the parts by weight of volatile matter in fresh solids and the second to volatile matter in ripe sludge). The ratios of seeding and the treatment of the different mixtures as well as the digestion time are given in Table III. It will be

TABLE III

	Fresh Solids–Ripe Sludge	Treatment	Digestion Time (Days)
1	2:1	None	14
2	2:1	Lime	12
3	2:1	Lime + alkaline salts	10
4	4:1	Lime + alkaline salts	11
5	4:1	Lime	11
6	8:1	Lime + alkaline salts	11
7	8:1	Lime	12

seen that the 2:1 mixture without any treatment required the longest time to digest (14 days). The lime treatment reduced the digestion time by 2 days and a further reduction of 2 days was brought about by the alkaline salts. When the quantity of raw material added was increased in relation to ripe sludge, the digestion time was not increased, as in the previous series, provided lime or lime and the alkaline salts were added. The addition of the alkaline salts plus lime did not prove of any additional value in this case.

The Reaction Adjustment of Fresh Solids.—Since it was shown that with the use of lime and alkaline salts the quantity of ripe sludge could be reduced materially without increasing the digestion time it was thought of interest to find out the effect of these salts in the thermophilic diges-

tion of fresh solids without ripe sludge. It has been shown in our earlier work[1] that the thermophilic digestion of fresh solids without seeding material is a very slow process. Will the addition of lime and alkaline salts reduce the time of digestion of fresh solids and hasten the production of ripe sludge? Is the use of artificial cultures of bacteria necessary in starting a new tank? Although the work done on the second phase of the problem is at present meager it will be reported for its interest.

Two sets of fresh solids were treated with lime and alkaline salts, one of which received in addition a "culture" of thermophilic bacteria. This was obtained by inoculating nutrient broth with a small portion of thermophilic sludge and incubating at 50° C. for three days. For comparison a similar culture was added to fresh solids without the lime and alkaline salts. The pH values were determined from a second series of bottles which were opened for this determination; gas measurements were made from unopened bottles. The pH values during the course of digestion, the yield of gas and the digestion time are given in Table IV. The solids

TABLE IV

Days	1 Lime + Alkaline Salts	2 "Culture"	3 Lime + Alkaline + "Culture"
		pH Values	
Initial	8.2	6.0	8.2
4	7.1	5.6	7.0
8	7.4	5.7	7.4
12	7.6	5.8	7.7
17	7.8	6.1	7.5
33	8.0	6.8	8.0
42	...	7.2	...
Digestion time, days	25	30[1]	23
Total gas, cc.[2]	710	50	765

[1] Discontinued at the end of 30 days.

[2] Per gram of raw volatile matter.

treated with lime and alkaline salts and initially adjusted to pH 8.2 did not drop below a pH value of 7.5. The reaction after 4 days moved rapidly toward the alkaline side and reached a value of 8.3 in 33 days. The addition of "culture" did not materially affect the changes in reaction. In the unadjusted fresh solids which received the "culture" the pH value dropped to 5.6 and had reached the value of 7.2 only after 42 days. The digestion was completed in 25 days in the solids treated with lime and alkaline salts. The use of "culture" in addition to lime and alkaline salts reduced the digestion time 2 days, *i. e.*, to 23 days. The unadjusted solids with the "culture" alone had digested to only a small extent in 30 days, as is indicated by the small amount of gas produced.

It is interesting to compare this series with the previous one in which the quantities of lime and alkaline salts added and the temperature of incubation were the same (50° C.). The use of ripe sludge even in greatly

reduced quantity results in a digestion time of 10–11 days provided the reaction is adjusted. With a similar adjustment of reaction but without any ripe sludge the digestion is completed in 25 days. The addition of "culture" of thermophilic bacteria does not materially reduce the digestion time. The difference in the digestion time should be ascribed to the superiority of ripe sludge both in regard to pH regulation as well as a "seed" material rich in organisms responsible for the digestion. Since the pH value of the fresh solids was regulated by the addition of lime and alkaline salts so that it would not drop below 7.0 and still the digestion time was twice as long as in the samples which contained small quantities of seeding sludge, it would seem that the inoculating value of the sludge was the more important factor. The reason why an artificial culture could not replace the sludge in this respect was probably due to the fact that the culture used did not represent and duplicate the flora of the sludge. From a practical standpoint on the other hand it is encouraging to note that in 25 days ripe sludge can be produced from fresh solids provided the reaction is controlled. This could not be accomplished under the most ideal non-thermophilic condition.

The Effect of Different Temperatures.—The effect of different temperatures, within the thermophilic range, on the digestion time of seeded mixtures is given in Table V. The rate of digestion at 55° C. and 60° C. may be somewhat more rapid than at 50° C. but it is doubtful whether the small differences will warrant the increase in the amount of heat. On the other hand, it may be possible to reduce the temperature to 45° C. without materially increasing the digestion time.[1] Increasing the temperature beyond 60° C. results in a retardation.

TABLE V

Temperature, ° C.	Digestion Time (Days)
50	14
55	11
60	12
65	27
70	26

TABLE VI

COMPARISON OF THERMOPHILIC AND NON-THERMOPHILIC DIGESTION

	50° C.	22° C.
Digestion time (days)	14	35
Gas produced, cc. per gm. raw vol. mat. added	850	790
Red. of vol. matter, %	42	34.3
Gas produced, cc. per gm. vol. mat. decomposed	2000	2320
Reduction of fats, %	61.0	66.0
Reduction of N, %	42.4	28.0
Fat and protein decomposed, % / Volatile matter decomposed	80	90

Comparison of Thermophilic and Non-Thermophilic Digestion.—Table VI gives summarized comparison of thermophilic and non-thermophilic digestion. It is interesting to note that the differences are marked not only in regard to the time of digestion but also in the degree of transformation of the component materials. A somewhat greater amount of gas is given off per gram of raw volatile matter under thermophilic conditions with a greater reduction of volatile matter. Gas produced per gram of volatile matter destroyed is, however, not as high in thermophilic digestion as at 22° Centigrade. The fats are decomposed equally well at high as at low temperatures, while the most striking differences are to be noticed in regard to the decomposition of the nitrogen compounds. Under thermophilic conditions a greater reduction of nitrogen takes place. The fat and the protein decomposed (N × 6.25) constitute 80 per cent of the volatile matter decomposed under thermophilic condition and 90 per cent at 22° Centigrade. These data indicate that the decomposition of substances other than fats and proteins takes place to a greater extent under thermophilic conditions. The nature of these substances is as yet unknown.

Effect of Temperature on Solids Concentration.—The effect of heating fresh solids on the concentration of sludge is shown in Table VII. Equal

Table VII

	22° C.	60° C.
Total height liquid + solid (inches)	$9^{3}/_{8}$	$9^{1}/_{2}$
Height solids (inches)	$5^{1}/_{4}$	$2^{7}/_{8}$
Liquid drawn off (grams)	50	100
Solids (%) after drawing off supernatant[1]	8.2	14.9

[1] Solids in the original fresh solids, 4.2%.

portions of fresh solids were placed in glass cylinders and incubated at 22° and 60° C. overnight. The height of solids was measured and the supernatant liquor drawn off from each and measured. It is apparent that more liquid separated at 60° than at 22° C., thereby increasing the concentration of solids from 8.2 to 14.9 per cent. The concentration of the original fresh solids was 4.2 per cent.

Discussion

The conditions necessary for the successful digestion of solids under thermophilic conditions are: (1) the proper temperature; (2) the proper seed sludge.

Each of these requirements entails a number of factors which should be discussed at some length. It has been shown that when these conditions are fulfilled the digestion is accomplished more rapidly than has been done heretofore. In fact the digestion time has been reduced to one-half of the most rapid digestion under laboratory conditions and to one-third of the time thus far considered feasible for plant operation.

It seems reasonable to assume that the digestion time of 12 days can be further curtailed if, instead of the "batch" process, quantities of fresh solids are added daily. The maximum allowable load with daily additions of fresh solids is being determined now under laboratory conditions. But it is a far cry from accomplishing such results in the laboratory, where the material is put into an electrically controlled incubator, to duplication of results in actual plant operation. How are such high temperatures actually to be created and maintained economically? The amount of gas produced at high temperatures is not only somewhat greater but it is produced in much shorter time, namely, at rates 2 to 3t imes as great as those obtained at lower temperatures. The size of tanks or the digestion capacity would be one-third of what is necessary at 22° C., provided the temperature could be raised to 45–50° Centigrade. After this high temperature was reached the gas production would go on at sufficiently rapid rate to maintain such temperature, provided heat losses could be prevented. The material would remain in the tank only one-third of the time, thereby counterbalancing to a certain extent the greater loss of heat caused by the higher temperature in the tank. If thermophilic tanks only one-third the size of present heated tanks are built with particular attention to the proper insulation of top and sides, heat losses could be reduced to a large extent. Since the composition of the gas is not materially affected by digestion at high temperatures[1] the heat value of the gas should be the same as at low temperatures. There would be greater concentration of solids at high temperatures than at low and greater reduction of volatile matter tending to decrease the size of tanks to a greater extent. It will be interesting to find out whether these generalizations and predictions will be borne out in actual practice.

In starting a new tank the problem of seed sludge will be felt most acutely. Ripe sludge from Imhoff tanks or separate sludge digestion tanks would be of certain value. Lime will further accelerate the production of sludge. It should be possible to put the tank in regular operation schedule within a month after starting. The amount of sludge to be maintained in the tank could be reduced without materially affecting the digestion time. This would result in a further decrease in the digestion capacity.

Summary and Conclusions

A series of laboratory experiments has been conducted with consideration of certain factors influencing the thermophilic digestion of fresh solids such as temperature, seeding and reaction control. The results seem to warrant the following conclusions:

1. Liming accelerates the rate of decomposition and makes it possible to reduce the quantity of sludge without causing a prolongation of digestion time.

2. Digestion of seeded mixtures can be accomplished in 12–14 days and if such a mixture is limed the quantity of seeding sludge can be reduced or the load of fresh solids increased fourfold without causing a retardation in time of digestion.

3. The digestion of fresh solids without seeding sludge can be accomplished in 25 days if the reaction is controlled so that it does not drop below a pH value of 7.0.

4. Digestion is slightly more rapid at 55–60° C. than at 45–55° C., but above 60° C. there is a retardation.

5. Gas yield, volatile matter reduction and decomposition of nitrogenous substances are greater under thermophilic conditions than at lower temperatures.

6. Solids concentrate to a greater extent at high temperatures than at lower temperatures.

References

[1] W. Rudolfs and H. Heukelekian, "Thermophilic Digestion of Sewage Solids," *Ind. Eng. Chem.* **22,** 96, Jan., 1930.

[2] H. Heukelekian, "Studies on the Function of Ripe Sludge." To be published in THIS JOURNAL.

Preliminary Studies of Thermophilic Digestion.—Sewage solids from Plainfield were digested at 37°, 45° and 55° C. There was practically no gas production from unseeded solids incubated at 45° and 55°; when seeded the rate at 37° was slow, but at 45° and 50° the peak was reached in 22 days. When these solids were again used for seeding, the rate of gas production was still further accelerated and completed within 18–20 days. There was an initial lag of about 5 days. Further use of the digested solids for seeding of fresh solids reduced the time for the peak of gas production to 11 days.

There are two types of flora effective in digestion, non-thermophilic having an optimum at 28° and thermophilic at 45–55°. Practical completion of gas production occurs in 26 days at the lower temperature and in 14 days in the thermophilic range. Total gas production is slightly greater and odors are more intense at 45–55°. Insulation of tanks is essential, but since gas production is so rapid and time of digestion so short, it may be possible to maintain temperatures without external sources of heat. W. Rudolfs and H. Heukelekian.—*Ind. Eng. Chem.*, **22,** 96–99, January, 1930.

The Oxygen Requirements of the Activated Sludge Process

BY S. GRANT, E. HURWITZ AND F. W. MOHLMAN*

In view of the aerobic nature of the activated sludge process, it is rather surprising to realize that practically no laboratory studies have been made of the oxygen requirements of the sludge, or the sludge, and sewage mixtures. There is considerable discussion in the literature of the rates of oxidation, minimum oxygen requirements, quantity of sludge required and other factors connected with the oxygen relations of the process, but so far as we know nothing has been published concerning the actual utilization of oxygen by sludge, or sludge and sewage taken from a plant in operation, and subjected to a period of aeration similar to those in activated sludge practice, namely, from three to six hours. There are many good reasons for this lack of information. In the first place, it is necessary to use fresh sludge from a plant in actual operation rather than sludge built up in the laboratory. Most plant chemists do not have time to carry on the tedious research necessary for a study of the oxygen requirements. Research workers may not be able to obtain fresh sludge suitable for experimental studies. In the second place, experimental difficulties in determining oxygen requirements over short periods of time are considerable. There are two general methods of attack, first, by direct absorption of oxygen and measurement of the decrease in volume of the gas, or, as a variation, measurement of the decrease in pressure; second, volumetric determination of dissolved oxygen at short intervals, either in the undiluted sludge or by means of the well-known dilution method for B. O. D. determination. A further discussion of the advantages and disadvantages of these methods of attack will be presented below.

It is of interest to consider the value of a knowledge of the oxygen requirements of activated sludge. Practically all investigators of the activated sludge process agree that the action of the sludge during the process of purification is primarily of biological nature, probably induced by enzymes produced by bacterial action. When one considers the clarification effect, however, some influence must be ascribed to a purely physical process of adsorption or, in common terms, the coagulation or "scrubbing out" of colloidal solids in the sewage liquor. Even here, however, biological agencies may be of great importance. If the clarification of sewage by activated sludge were purely physical it would undoubtedly be desirable to maintain a high concentration of activated sludge in the aeration tanks. We know, however, that activated sludge does require oxygen, probably

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in proportion to its concentration. There is, therefore, a limit to the concentration which should be maintained. There should be enough sludge to obtain maximum adsorption and clarification, but not so much sludge that the oxygen requirements will be in excess of the oxygen that can be absorbed from the applied air.

These considerations have led to the development of two-stage processes, in the first of which a large amount of sludge is used in order to obtain the benefit of mass action for clarification, while in the second stage a small amount of sludge is used in order to reduce the oxygen requirements. In America the tendency has been to carry rather large concentrations of sludge, while in England lower concentrations are recommended.

The amount of sludge present in the aeration tanks has usually been reported volumetrically according to the amount settling in graduated cylinders after one or two hours of quiescent sedimentation. Experience in operating a plant soon shows the inaccuracy of this method of control. The sludge may suddenly bulk to double its previous volume, although containing the same actual weight of suspended solids. Because of these variations, for some years we have been making gravimetric determinations of suspended solids in the aeration tanks of our treatment plants and giving a daily report of the parts per million suspended solids in the tanks. Concentrations of from 3000 to 5000 p. p. m. are usually carried, although when the sludge bulks these concentrations may run down to 1500 p. p. m. or less. In a study of the oxygen requirements of activated sludge it is evident that the actual weight of sludge must be known rather than the percentage of sludge in the mixed liquor. If we could correlate the daily determination of oxygen requirements of sludge with the actual weight of sludge in the aeration tanks it might be possible to develop a more rational basis for determination of the amount of sludge to be returned and maintained in the aeration tanks. It therefore seems to us that it is very desirable to obtain more information concerning the oxygen demand of activated sludge.

We have carried on considerable experimental work toward this end and are continuing our studies. In view of the large amount of experimental data, we will present in this paper only a description of the apparatus and the results obtained on activated sludge and sewage from the North Side Treatment Works of the Sanitary District of Chicago.

Experimental Technique

The two methods of attack of this problem were mentioned above. The absorption of gaseous oxygen is used in the apparatus devised by Sierp[1] and can also be used in the apparatus devised by Theriault.[2] We have used the Sierp apparatus and have also devised a modification designed to increase the accuracy of this procedure.

In measuring the volume of oxygen absorbed by sludge it is necessary to keep the sludge in constant suspension, to maintain oxygen in the liquor, to absorb any CO_2 produced, to correct volumes absorbed according to temperature and pressure and, above all, to prevent leaks in a rather complicated apparatus undergoing vigorous agitation. These requirements make it very difficult to use methods which depend on measurement of the decrease in volume of a gas. The Sierp apparatus must be mounted on a shaking machine in order to maintain constant suspension of the sludge; all CO_2 must be absorbed by a solution of sodium hydroxide which must be prevented from entering the absorption pipette and into which the absorption of CO_2 is very slow on account of the small surface exposed; the amount of oxygen in the solution must be determined at the beginning and end of experiments in order to correct for any variation; the partial pressures of nitrogen (dissolved in the sludge) and oxygen vary, so that whenever oxygen is added the rates of absorption increase, due to its greater partial pressure; finally, it is very difficult to prevent leaks through the rubber tube connections on the absorption bulb while it is being agitated. We modified the Sierp apparatus by installing a larger gas burette with a considerably greater capacity and more accurately calibrated than that of the Sierp burette, with a movable reservoir for raising and lowering the level of the sodium hydroxide, thus obtaining more complete absorption of CO_2. While this was somewhat more satisfactory than the Sierp apparatus, the technique was still difficult and there were discrepancies between various runs on activated sludge.

It was our conclusion that in order to obtain satisfactory technique it would be desirable to devise an apparatus in which the dissolved oxygen could be measured at short intervals of time by accurate volumetric determinations. The apparatus finally devised is described below.

Description of Apparatus and Determinations

The apparatus used in these experiments is shown in Figures 1 and 2. A definite volume of water or sewage which had previously been aerated with oxygen is put into the five-gallon carboy A, through the opening at *h*. Then a definite volume of sludge is added. The stopper *h*, through which tubes for oxygen and for removal of samples have been passed, is immediately put in place and the stirrer is operated rapidly. The pinch-clamp at *i* is left open until the air above the liquid in *A* is completely displaced by oxygen. Clamp *i* is then closed and the pinch-clamps *d* and *g* are removed. The mixture in *A* passes through tube *c* and tube *e* into the cylinder, displacing the air through *g*. The pinch-clamp at *g* is closed and *f* is opened long enough to fill the tube. The stirrer in the cylinder is then started in motion. At this instant the initial time is

recorded and thereafter samples are removed at definite time intervals from tubes *a* and *f*.

Two samples are collected in 300-cc. volumetric flasks, into which one cc. of concentrated sulphuric acid has been added, in order to check bacterial action. To take a sample from the cylinder the stirrer is stopped and 300 cc. of liquid are withdrawn through tube *f*, which reaches about two inches into the liquid. At the same time, *d* having been left open, 300 cc. of liquid are drawn into the cylinder from *A* through tube *e*, which reaches to the bottom of the cylinder, thus preventing mixing of the incoming and outgoing liquids. Immediately after withdrawal of the sample the stirrer is started and the liquid in the cylinder is mixed uniformly. At the same time a sample is taken from *A* through *h* but the stirrer is not stopped, there being no need to prevent stirring. Both samples are allowed to stand seven minutes, after which the supernatant liquor is siphoned off into 125-cc. bottles and the dissolved oxygen determined. Samples for analyses and B. O. D. determination are also withdrawn at intervals.

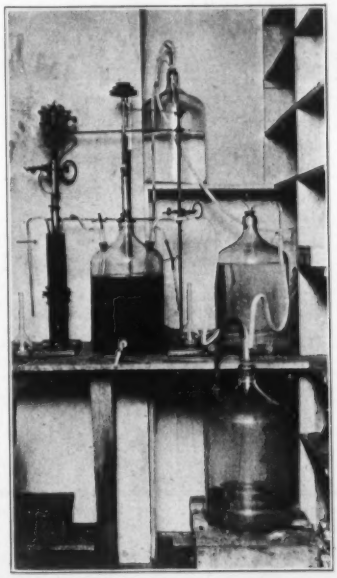

FIG. 1.—Apparatus Used for Measurement of Absorption of Oxygen by Activated Sludge.

The weight of oxygen absorbed is calculated from the determinations of dissolved oxygen in the samples drawn from *a* and *f*. The volumes of the cylinder and the sample withdrawn from it are known; the initial dissolved oxygen of the sludge in the cylinder is computed as follows:

Total cc. of sludge in cylinder = B
Cc. withdrawn from cylinder = C
D. O. in sample withdrawn from cylinder B = X (p. p. m.)
D. O. in sample withdrawn from carboy A = Y (p. p. m.)

$$\frac{(B - C)X + Cy}{B} = \text{initial D. O. in p. p. m.}$$

After intervals of from 10 to 30 minutes a sample is withdrawn from *B* as described above. The D. O. content is subtracted from the initial computed result, to give the depletion; the D. O. result (X) is used in the formula given above to compute the initial dissolved oxygen content for the next time interval. This process is repeated until the end of the experiment.

The suspended solids, total, volatile and fixed, were determined in all experiments, so that oxygen absorptions might be calculated to the basis of dry sludge and corrected even further for the content of organic matter.

Typical data and computations for one experiment are shown in Table I.

TABLE I

ABSORPTION OF OXYGEN BY ACTIVATED SLUDGE

Capacity of cylinder = 1080 cc.
Volume of dilution water = 14200 cc.
Volume of sludge = 2000 cc.

Time in Minutes	D. O. Cylinder, P. p. m.	D. P. 5-Gal. Carboy, P. p. m.	D. O. Initial, P. p. m.	Oxygen Absorbed, P. p. m.	Total Oxygen Absorbed from Beginning of Experiment, P. p. m.	Mg. Oxygen Absorbed per Gram of Dry Activated Sludge
0	25.8	25.8	...	..	...	..
15	20.4	25.0	25.8	5.4	5.4	1.913
30	17.5	24.7	21.64	4.14	9.54	3.402
45	15.1	26.8	19.50	4.4	13.94	4.930
60	13.6	28.2	18.32	4.72	18.66	6.59
90	9.3	31.8	17.62	8.32	26.98	9.57
120	7.9	37.3	15.4	7.5	34.48	12.31
135	11.6	36.4	15.96	4.36	38.84	13.76
155	14.8	38.0	18.42	3.62	42.46	15.07
170	14.5	39.8	21.14	6.64	49.10	17.37
200	14.8	39.3	21.46	6.66	55.76	19.91
230	14.4	36.7	21.52	7.12	62.88	22.19
260	14.8	29.9	21.52	6.72	69.60	24.61
290	14.7	39.0	21.52	6.82	76.42	27.09

Dry solids in sludge = 2.29%
Dry solids per liter = 2.826 grams

Results of Experiments

Absorption of Oxygen by Sludge.—Activated sludge from the North Side Treatment Works was used in these tests. Sludge was collected at the effluent end of the aeration tanks, concentrated by settling or diluted with water in the laboratory when necessary. The content of suspended solids, from 1225 to 4850 p. p. m., covers the usual range in the North

Side aeration tanks. The sludge was saturated with oxygen before starting each test, consequently no immediate demand was exerted.

The determinations of oxygen depletion were made at intervals of from 15 to 30 minutes up to 290 minutes. The apparatus was set up in our 20° C. room. The results of five experiments are shown in Table II and Figure 3.

The curves in Figure 3 appear to be almost straight lines but they are actually slightly convex, indicating a decreasing rate of oxygen absorption. The accuracy of this technique is shown by the slight deviations of individual results from the smooth curve drawn through the points as plotted.

The relation between oxygen absorbed and concentration of sludge is shown in Figure 4 at various time intervals up to 180 minutes. A straight-line relation is apparent, indicating that the oxygen consumption varies in proportion to the weight of sludge used. This result is of interest since it might be thought that the more dilute sludge would require proportionately more oxygen, if the rate of absorption depended on surface rather than mass.

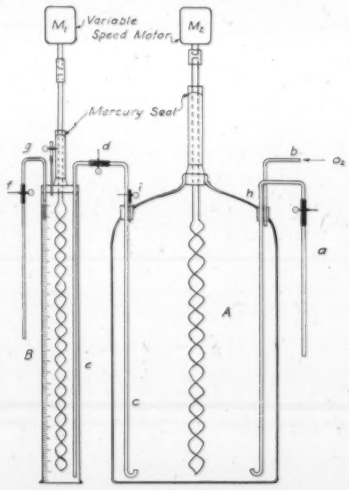

FIG. 2.—Diagram of Apparatus.

If the results shown by the various curves in Figure 3 are calculated to rates of absorption in milligrams of oxygen per gram of sludge, the curves shown in Figure 5 will be obtained. It is apparent that the rate of absorption varies. This variation is to be expected since the activated sludge used was collected at intervals over a period of a month. During this time the period of retention of sludge in the tanks varied, likewise the degree of digestion of organic matter, the state of activation, and other properties of the sludge. However, if we tabulate the per cent of volatile matter in the sludges used in these tests, it will be found that the higher rates of oxygen absorption shown in Figure 5 correspond with larger contents of volatile matter. This relation is shown more clearly in Figure 6, in which rate of absorption is plotted against content of volatile matter.

TABLE II
OXYGEN DEMAND OF ACTIVATED SLUDGE

Experiment	1		2		3		4		5	
Date	Dec. 12, 1929		Nov. 29, 1929		Dec. 16, 1929		Nov. 25, 1929		Dec. 16, 1929	
G. per Liter	1.225		1.624		2.53		2.826		4.85	
Per Cent Vol. Matter (Dry Basis)	67.6		67.8		67.2		67.4		67.2	
Time Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed Dry Basis, Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis, Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge
20	2.62	2.13	30	6.88	4.25	20	5.56	2.20	15	5.4	1.91	15	7.66	1.58
50	7.00	5.71	60	13.32	8.22	40	10.98	4.34	30	9.6	3.40	25	12.66	2.61
80	11.38	9.29	90	18.70	11.50	60	15.88	6.28	45	14.0	5.93	35	17.72	3.65
110	15.74	12.84	120	24.16	14.84	80	21.20	8.38	60	18.6	6.59	45	22.46	4.63
140	19.36	15.80	150	29.32	18.00	100	25.92	10.25	90	27.0	9.57	55	26.76	5.52
170	23.20	18.94	180	33.98	20.83	120	30.52	12.07	120	34.6	12.31	65	30.92	6.38
			210	38.68	23.81				135	38.8	13.76	75	34.94	7.21
			240	42.80	26.35				155	40.4	15.07	85	40.50	8.35
			270	47.44	29.15				170	49.0	17.37	95	44.86	9.25
									200	55.6	19.91	105	49.06	10.12
									230	62.6	22.19	120	55.96	11.52
									260	69.4	24.61			
									290	76.2	27.09			

TABLE III

OXYGEN DEMAND OF ACTIVATED SLUDGE PLUS SEWAGE

Experiment	6			7			8			9			10			11		
Date,	Dec. 17, 1929			Dec. 18, 1929			Dec. 11, 1929			Dec. 20, 1929			Dec. 4, 1929			Dec. 23, 1929		
G. per Liter	4.74			3.65			2.09			1.97			1.55			0.92		
Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge		Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge	Time, Min.	O_2 Absorbed, P. p. m.	O_2 Absorbed, Dry Basis Mg. O_2 per G. Sludge
7	5.12	1.1		15	8.5	2.35	8	2.9	1.4	10	4.3	2.1	5	3.6	2.3	15	2.4	2.6
17	12.04	2.5		30	16.3	4.5	23	8.7	4.2	30	14.6	7.4	15	7.4	4.7	30	6.8	7.4
27	18.02	3.8		50	26.1	7.2	38	14.6	7.0	50	21.4	10.8	30	12.5	8.0	45	10.0	10.9
37	23.10	4.9		65	32.8	9.0	53	18.7	9.2	75	28.5	14.5	45	16.3	10.5	75	15.0	16.4
47	28.18	5.9		75	37.5	10.3	69	23.9	11.4	100	36.4	18.4	60	20.0	12.7	105	19.6	21.5
57	33.28	7.0		85	42.3	10.8	83	29.2	14.0	125	44.2	22.4	75	23.9	15.3	135	24.0	26.2
72	40.44	8.5		95	46.0	12.6	98	32.4	15.5	150	50.7	25.6	105	31.2	20.0	165	28.8	31.4
87	47.67	10.1		110	52.3	14.3	113	36.1	17.3				135	37.9	24.3			
102	54.48	11.5		125	59.3	16.2	128	40.4	19.4				165	44.6	28.9			
117	61.86	13.1		140	65.5	17.9	143	44.8	21.5				195	50.4	32.4			
132	68.30	14.4		160	72.3	19.8	158	48.2	23.1				228	56.1	36.9			
147	75.24	15.9		180	80.1	21.9	173	52.5	25.2									
162	82.10	17.3																

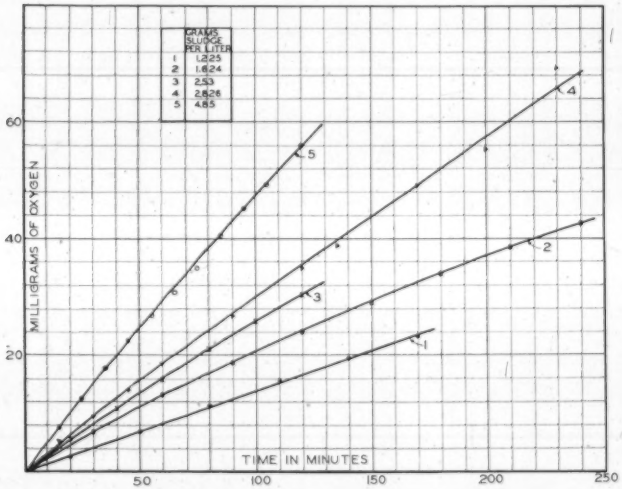

FIG. 3.—Absorption of Oxygen by Activated Sludge, as Determined.

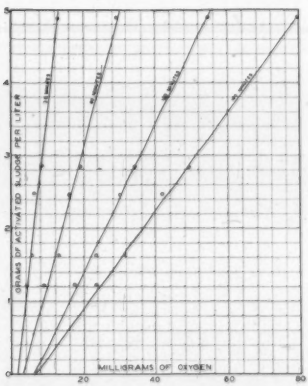

FIG. 4.—Absorption of Oxygen by Activated Sludge at Various Intervals of Time.

It is seen that the rate varies from 6.0 to 7.4 mg. oxygen per gram of sludge per hour for the sludges used in these tests.

Absorption of Oxygen by Sludge and Sewage.—Sewage and activated sludge from the North Side Treatment Works were used. The sewage was settled and rapidly filtered through glass wool in order to remove the coarser suspended matter. Activated sludge was added to the sewage in varying amounts and experiments performed in the same manner as those described in the first part of this report. The results of six experiments are shown in Table III and Figure 7 for amounts of sludge ranging

from 0.918 to 4.74 grams per liter. The rate of absorption increases with concentration of sludge. For example, the same amount of oxygen (50 mg.) is absorbed in 210 minutes by 1.55 grams per liter sludge as in 105 minutes by 3.65 grams per liter sludge.

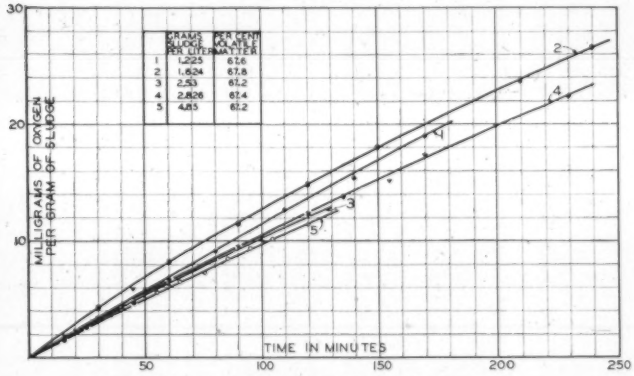

FIG. 5.—Absorption of Oxygen per Gram of Activated Sludge.

The results shown in Figure 7 have been calculated to the rate of absorption per gram of sludge as shown in Figure 8. In this curve the rate of change is shown to increase in inverse proportion to the concentration

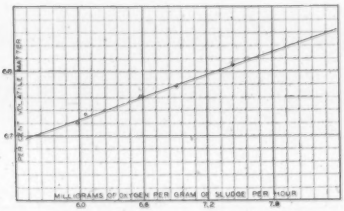

FIG. 6.—Correlation of Volatile Matter in Activated Sludge and Rate of Absorption of Oxygen.

of sludge. A curve showing the average absorption per gram of sludge without sewage, as reported in Figure 5, is drawn on Figure 8, and the

differences between this curve and those obtained for sewage and sludge are plotted in Figure 9 to show the amount of oxygen absorbed by sewage in the presence of various amounts of sludge. The curve of oxygen absorption for sewage plus sludge in Figure 8 almost coincides with the curve for sludge alone when using 4.74 grams per liter. In fact, the sludge curve slightly exceeds the sludge plus sewage curve after 100 minutes. These differences are probably within the limits of experimental error. The sludge plus sewage curves using lower amounts of sludge are considerably above the curve for sludge alone.

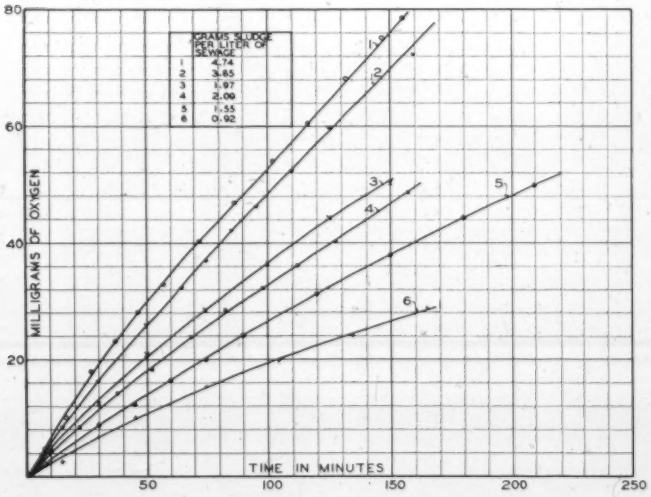

FIG. 7.—Absorption of Oxygen by Activated Sludge Plus Sewage, as Determined.

Five-day B. O. D. determinations were run on samples taken at intervals during the experiments on sewage plus sludge. These samples were filtered through glass wool in order to remove large flocs of activated sludge. The percentage reductions as calculated are shown in Figure 10. It is unfortunate that the same sewage and sludge could not be used in all tests and for this reason the initial B. O. D. results varied somewhat, although all samples were quite dilute.

Determinations of organic, ammonia, nitrite and nitrate nitrogen

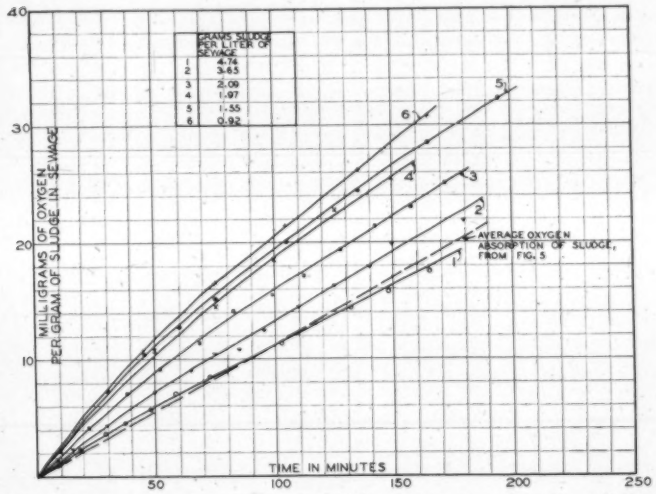

FIG. 8.—Absorption of Oxygen by Activated Sludge Plus Sewage, per Gram of Sludge.

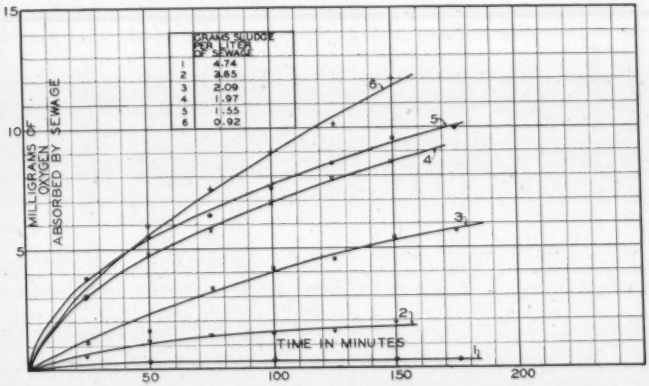

FIG. 9.—Absorption of Oxygen by Sewage Alone, in Presence of Activated Sludge.

were made at intervals for several tests but results are not sufficiently conclusive to warrant publication without further data. The results indicated, however, that larger amounts of sludge accelerated nitrification,

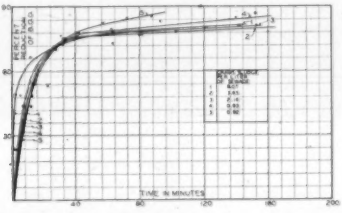

FIG. 10.—Percentage Reduction of B. O. D. of Sewage in Presence of Various Amounts of Activated Sludge.

as would be expected under such intensive aerobic conditions, but even in the presence of 8.07 grams of sludge per liter less than 2.0 p. p. m. nitrate was formed during the first two hours.

Discussion

Absorption of Oxygen by Sludge.—The sludge used in these experiments was collected at the North Side Treatment Works in November and December, 1929. There was an average of 3800 p. p. m. suspended solids (activated sludge) in the aeration tanks, and the aeration period averaged 5.9 hours.

The average rate of oxygen absorption of the sludge used in our experiments is approximately 7.0 mg. of oxygen per gram of sludge per hour. The sludge in the aeration tanks, 3800 mg. per liter, therefore used $3.8 \times 7.0 = 26.6$ p. p. m. oxygen per hour or a total of 157 p. p. m. during the 5.9 hours of aeration. The removal of 5-day B. O. D. from the sewage by the activated sludge process averaged 100 p. p. m. This comparison indicates that the sludge absorbed more oxygen during aeration than would be required for the 5-day or even the total B. O. D. (first stage) of the sewage applied. However, as shown in the curves for sewage and sludge, a large amount of colloidal matter of the sewage is adsorbed by the sludge and the material so adsorbed is not completely oxidized during a single passage through the tank. As a matter of fact, the solids adsorbed from the sewage remain in the aeration tank for very long periods. For example, the suspended solids removed at the North Side Plant averaged approximately 93 p. p. m. If we compare the weight of solids removed

from the sewage daily with the weight of circulating sludge, the computations indicate that it would require about 15 days to displace completely one day's accumulation of solids. During this 15-day period the adsorbed material is slowly oxidized by repeated passages through the aeration tanks. The proportion of the solids in sewage oxidized during a single passage through the tanks, as compared with the amount oxidized during the total retention period, depends upon the amount of sludge maintained in the aeration tanks. If large amounts of sludge are used, practically all of the oxygen requirement is carried by the sludge with a very small proportion required by the liquid portion of the sewage treated.

These relations indicate that the amount of sludge carried in the aeration tanks is quite important from the standpoint of oxygen, or air required. Calculations of the rate of oxygen requirements must take this factor into account.

Jenks and Levine,[3] in connection with their studies of "stream-flow" aeration, have discussed the theoretical oxygen requirements of the activated sludge process on the assumption that the rate of air supply should be adjusted to the diminishing demand in proportion to the theoretical rate of satisfaction of oxygen demand as proposed by Phelps[4] and later more fully confirmed by Theriault.[5] The logarithmic nature of this rate curve is well known; as expressed by Phelps, "the rate of biochemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms of oxidizability." Jenks and Levine, in considering the 5-day demand, apportion the requirements for oxygen as follows:

Days	Per Cent	Per Cent Per Day
1	60	60
2	84	24
3	94	10
4	98	4
5	100	2

The rate of B. O. D. satisfaction is assumed to correspond to the rate of aeration, directly as above if the aeration period is 5 hours, or proportionately allocated if the aeration period is greater or less.

According to this theory it would be correct to apply during the first hour 60 per cent of the total air used for activated sludge treatment, 24 per cent during the second hour and 16 per cent during the last three hours, for a total 5-hour aeration period. This procedure would be radically different from the present practice of using a constant rate throughout the aeration tanks.

Our results indicate that the rapidly decreasing rate indicated by the theory of Jenks and Levine would not obtain in the presence of activated

sludge, but that the rate would be much more nearly uniform from start to finish of a single-stage process of aeration.

Absorption of Oxygen by Sludge and Sewage.—The curves shown in Figure 7 indicate that considerably more oxygen is required in the presence of large amounts of sludge, but as shown in Figures 8 and 9 the amount used for the unadsorbed portion of the sewage is almost negligible when as much as 4.74 grams of sludge per liter are used. The curves of Figure 9 indicate that the adsorption of oxygen-demanding substances is greatly increased by increasing the proportion of sludge. By transferring this material to the sludge with its fairly uniform rate of oxidation extending over a long period, it should be possible to accomplish the purification of the sewage in a shorter interval. In this connection Harris, Cockburn and Anderson[6] claim that the time of treatment varies inversely with the amount of sludge used, within rather wide limits. With a shortened period of aeration, however, the period of reaeration of the sludge must be increased, for, as Harris and Cockburn put it, the "pollute" is transferred from the sewage to the sludge. The curves for Figure 9 show that with large amounts of sludge practically all of this "pollute" is transferred to the sludge. The curves shown in Figure 10 indicate, however, that there is very rapid removal of B. O. D. both with small and large amounts of sludge. These results suggest that, contrary to the theory of Harris, Cockburn and Anderson, the rate of purification is not accelerated directly in proportion to the amount of sludge. We expect to check these results by further work, using identical samples of sewage and sludge. It is possible that the rapid adsorption by small amounts of sludge might not be maintained if the tests were repeated continuously. Under such conditions reaeration of the sludge would become essential.

We expect to do further work to demonstrate these relations. When large amounts of sludge are carried in the aeration tanks and there is a long period of retention it is reasonable to assume that the rate of aeration should be more uniform than when small amounts of sludge are used and the period of retention is short. From a practical standpoint there are other advantages in maintaining large amounts of sludge, namely, the ability to withstand sudden changes in the composition of the sewage treated, prevention of bulking, and rapidity of oxidation.

The effect of large amounts of sludge is a fairly rapid adsorption of suspended and colloidal solids and a very slow subsequent oxidation of the adsorbed material. With small amounts of sludge the adsorption is not so great and the initial rate of oxidation of unadsorbed colloidal matter is increased. Our results, as well as those of others, indicate that initial adsorption takes place quite rapidly, that is, within 15 or 20 minutes. It would therefore seem logical to utilize this property of the

sludge in the first stage, maintaining the activity of the sludge by re-aeration. This is in accord with the theory of Harris, Cockburn and Anderson. Under such conditions it follows that the air supplied during this preliminary stage must be at a fairly high rate in order to insure the maintenance of aerobic conditions. After this initial stage the rate of aeration could be greatly reduced so that there would be only enough to satisfy the requirements of a small amount of sludge, which would absorb oxygen at a fairly uniform rate. The determination of the relation of sludge in both stages to the amount of air in both stages will depend upon the composition and concentration of the sewage treated and the quality of the effluent desired.

Our work so far has been confined to activated sludge and sewage from one plant. We intend to extend it to work on sludge and sewage from other plants in order to develop, if possible, a more rational theory to apply in general to the problems of returned sludge, weight of sludge carried in aeration tanks, necessity for reaeration of sludge and effect of the use of pure oxygen as compared with the use of air.

Conclusions

Our experiments with activated sludge and sewage from the North Side Treatment Works indicate that:

1. The rate of absorption of oxygen by activated sludge, in the amounts and periods of aeration commonly used, is fairly uniform, and varies directly in proportion to the weight of sludge.

2. The rate of absorption of oxygen varies, further, in proportion to the content of organic (volatile) matter in the sludge.

3. The rate of absorption of oxygen by North Side activated sludge averaged approximately 7.0 milligrams of oxygen per gram of sludge per hour.

4 Mixtures of sewage plus sludge absorb oxygen in proportion to the weight of sludge, but with increasing amounts of sludge most of the oxygen-demanding material of the sewage is coagulated or adsorbed by the sludge, so that very little oxygen is required for the unadsorbed material in colloidal or true solution. The subsequent rate of oxidation of the coagulated material in the sludge is slow and comparatively uniform. The sludge passes through many cycles of aeration before it is removed, and during these successive aerations the organic matter is slowly oxidized.

5. Based on reduction of B. O. D. our results so far do not indicate that the period of aeration and amount of sludge vary inversely (that is, that the period of aeration $\times$ per cent of sludge = constant) as claimed by Harris, Cockburn and Anderson. Small amounts of sludge reduced the B. O. D. of the sewage almost as rapidly as large amounts. Re-

aeration of sludge is indicated, however, when small amounts are used because of the shorter period of retention.

6. Adjustment of the rate of air supply should be governed by the amount of sludge in the aeration tanks. With large amounts a fairly uniform rate is desirable. Rates of aeration in proportion to the B. O. D. of sewage, as recommended by Jenks and Levine, are greatly modified by the oxygen requirements of the sludge.

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[1] F. Sierp, "A New Method for Determining Biochemical Oxygen Demand," *Ind. Eng. Chem.*, **20,** 247 (March, 1928).

[2] E. J. Theriault, "Apparatus for the Study of Biochemical Oxidations," U. S. Public Health Service Reports, **44,** 2257–2267 (Sept. 20, 1929).

[3] H. L. Jenks and Max Levine, "A Stream-Flow Sewage-Treatment Process," *Eng. News-Record*, **100,** 808–813 (May 24, 1928).

[4] E. B. Phelps, "The Disinfection of Sewage and Sewage Filter Effluents," U. S. Geol. Survey, *Water Supply Paper* **229,** 74–78 (1909).

[5] E. J. Theriault, "The Oxygen Demand of Polluted Waters," U. S. Public Health Service, *Bulletin* **173,** 1–185 (1927).

[6] F. W. Harris, T. Cockburn and T. Anderson, "Observations on the Biological and Physical Properties of Activated Sludge," *The Surveyor* **70,** 30–31 and 53–55 (July 9–16, 1926).

Stream-Flow Aeration.—A recent paper by Harry N. Jenks elaborates the principles of stream-flow aeration as conceived by Jenks and Levine. Mechanical aeration is considered to be superior to diffused-air treatment for industrial wastes. Stage treatment is advocated, with the rate of circulation regulated in accordance with the oxygen requirements of the sewage. For example, if in a 6-hour period there are three stages of 1.0, 1.5 and 3.5 hours, respectively, the number of displacements of the sewage volume should be 26.4, 16.0 and 7.6 in a total of 50 for complete treatment. Assuming 7.0 p. p. m. oxygen to be absorbed during each displacement, this procedure should satisfy a B. O. D. of 350 p. p. m. A diagram of a suggested type of stream-flow aeration tank shows a central air-lift tube, with surface trays for flow of the circulated sewage and sludge in thin films.

The second section of the paper deals with a de-cloggable biological filter designed to be back-washed by plant effluent. A depth of 3 ft. is suggested, with the upper third composed of $^1/_2$-in. stone. The intervals of washing may vary from twice a week to once in two weeks. The filter is of most value for preliminary treatment of industrial wastes.—*The Surveyor*, **77,** 351–353, March 14, 1930.

Effect of Temperature on Rate of Settling of Sewage Solids[1]

BY G. M. RIDENOUR[2]

It is known that temperature changes will affect the rate of settling of particles in a liquid medium as determined by the respective change in density of particles and settling medium, and by the change in viscosity of the medium, but precise data to determine the magnitude of this effect on sewage particles do not seem to be available. It has been the general observation that the higher the temperature of the settling medium the greater the rate with which the particles fall. Accordingly, greater efficiencies should be obtained in sewage settling tanks at high than at low temperatures. It has been observed at one or two plants that greater efficiencies were obtained from the sedimentation tanks in summer than in winter. The cause for this increased efficiency in these cases has been attributed to the higher temperature of the sewage in summer.

This paper records experiments which have been made to determine the effect of different temperatures on the rate of settling of sewage solids.

Apparatus

The settling apparatus consisted of 3-in. diameter cylindrical glass tubes, 36 in. long, with conical bottom. The outlet arrangement at the bottom of the cone permitted the settled solids to be drawn off at will.

Incubators were available for obtaining and maintaining the different temperatures selected for the experiment.

Methods

A composite sample of sewage was obtained from the Plainfield Plant at a point between the screens and the inlet end of the sedimentation tanks. Total suspended solids in the sample ran 250 parts per million. The sample was allowed to stand until all settleable material had settled to the bottom. The supernatant liquid was then siphoned off. The sewage liquid and sewage solids were each divided into a number of equal portions to provide samples for the different temperature runs desired. In the division of the solids care was taken to maintain as much uniformity of samples as possible by removing large particles of paper or other suspended matter. Settling tests were made at temperatures of 7°, 15°, 20°, 30°, 33° and 37° C. The solids settled at the end of predetermined

[1] *Journal Series Paper, New Jersey Agricultural Experiment Station, Department of Sewage Disposal.*

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intervals were drawn from the bottom of the settling tubes, dried and weighed. The suspended solids in the supernatant liquid were also determined at the end of each run.

Results

Figures 1, 2 and 3 show the results obtained. Figure 1 shows the per cent of total suspended solids removed at the end of different intervals

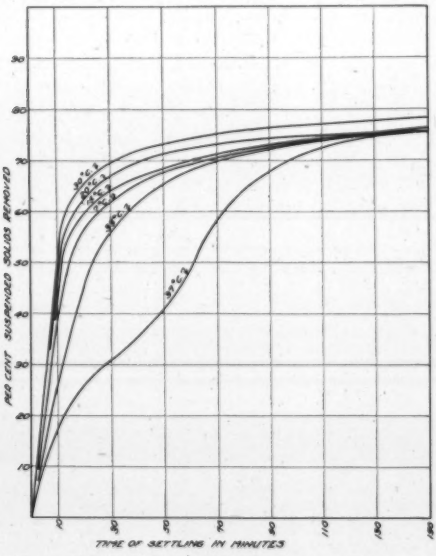

FIG. 1.—Effect of Time and Temperature on Removal of Suspended Solids.

of time for the different temperatures of sewage.

In Figure 2 curves have been plotted showing the average removals grouped between 1° and 30°, inclusive, 30° and 33°, inclusive, and 33° and 37° C. Figure 3 shows a comparison of percentage removal at various temperatures at the end of different intervals of time. The sewage density at the different temperatures is also shown.

Discussion

The results indicate that the temperature of sewage has an effect on the rate of settling of sewage solids, resulting in an increasing efficiency of settling with increasing temperatures up to a critical temperature, above which the efficiency rapidly falls off. This critical temperature appears to be between 30° and 33° C.

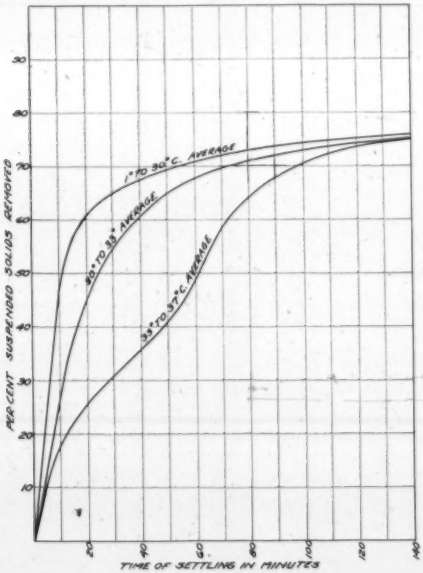

FIG. 2.—Removal of Suspended Solids at Various Average Ranges of Temperature.

However, on the basis of two hours' settling time the effect of temperature is negligible from the standpoint of removal of solids. The per cent removal at the end of two hours is practically the same at all temperatures. In the usual range of temperatures encountered in sewage the effect of temperature is of no practical importance even with a settling time less than two hours. Only in an unusual case where the sewage temperature might be above 30° C. and combined with a short detention period would the settling efficiency be materially decreased. Although this latter con-

dition is exceptional, at least one case is known where difficulties in settling of sewage at 21–40° C. were encountered. This plant received hot wastes from industrial plants.

Although it is generally assumed that temperature has a greater effect on the rate of settling of the finer particles suspended in sewage, the results of these experiments would not tend to support such an assumption. The efficiencies of settling at all temperatures were practically the same at the end of a two-hour period. The total suspended solids in the liquid

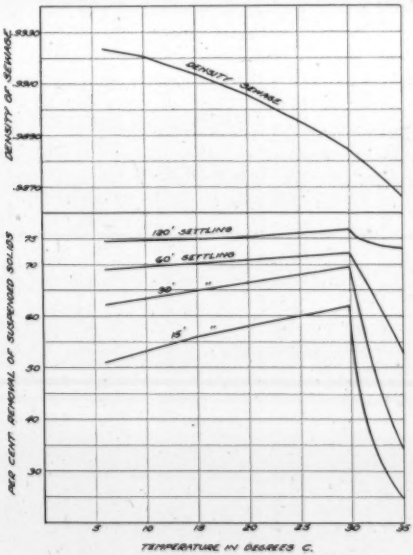

FIG. 3.—Density of Sewage and Effect of Critical Temperature on Settling Rate of Suspended Solids.

at the end of two hours were practically the same at all temperatures. This means that the effect of temperature on the settling of the finest or more colloidal particles in sewage is negligible, from a practical standpoint. The greatest effect is shown on the larger particles which settle in thirty minutes, as shown in Figure 3. This effect, however, is not large within the normal range of sewage temperatures.

While the critical temperature at which the settling rate of the solids

decreases is beyond the usual range of temperature of sewage, it is interesting to note some of the accompanying physical conditions occurring at these higher temperatures (33° and 37° C.).

Less flocculation of particles occurred at higher temperatures. A small portion of the solid material rose to the surface of the sewage liquid. This was settled by continuous stirring on the surface. The particles settled in a more finely divided state and did not flocculate to the extent noticed in settling at lower temperatures.

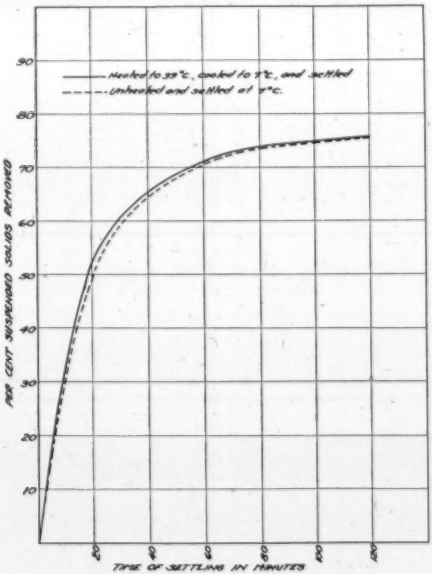

Fig. 4.—Effect of Heating and Subsequent Cooling on Efficiency of Settling of Suspended Solids.

The change which caused the particles to settle at a slower rate was not permanent. This was shown by a run in which the sample had first been heated to 37° C., then cooled to 7° C. and settled at that temperature. The settling material assumed almost identically the same settling characteristics of sewage settled at 7° C. that had not been first subjected to the high temperature. This comparison is shown in Figure 4.

Summary

Raw screened sewage was settled at different temperatures ranging between 1° and 37° C. to determine the effect of different temperatures on the rate of settling of sewage solids. From this experiment the following conclusions were drawn:

1. Temperature affects the rate of settling of sewage solids. The rate of settling increases slightly with corresponding increase of temperature up to 30° C. Near that point a critical temperature is encountered above which the rate of settling rapidly decreases.
2. Although temperature influences the rate of settling, its effect is of no practical importance in the usual range of temperatures encountered in sewage treatment.
3. The effect of temperature on the settling rate is most pronounced for settling periods of from 0 to 30 minutes.
4. The settling of the finer particles was not influenced by temperature.
5. Temperature of sewage is of no importance in the settling efficiency of a sewage settling tank unless a combination of high temperatures above 30° C. and short detention period prevails.
6. At the end of two hours the removal of solids by settling is practically the same for all temperatures between 1° and 37° C.
7. Less flocculation of sewage particles seems to occur at higher temperatures than at lower temperatures. At higher temperatures the sewage particles settle in a finely divided state. At the lower temperatures, below 30° C., a more pronounced flocculation of particles was noticed.
8. The change which caused the particles to be retarded in their settling rate at temperatures above 30° C. was not permanent. Sewage which was heated to 33° or 37° C. and then cooled to the lower temperature of 7° C. assumed the same settling characteristics as those of sewage settled at 7° C. without heating.

Ordinary Chloroform as a Sewage Preservative Increases Oxygen Consumed Values

BY R. T. HOMEWOOD* AND H. W. RUF**

The use of ordinary chloroform[1] as a preservative for sewage and trade wastes during the period between collection of the sample and laboratory analysis, is responsible for error in the laboratory determination of oxygen consumed (permanganate reduction) values.

Attention was drawn to this fact during the past summer when the authors, who were stationed at a field experiment station for the Wisconsin State Board of Health, were unable to reconcile their field values of oxygen consumed with those obtained at the State Laboratory of Hygiene at Madison. The field tests were run on samples prior to the addition of chloroform, while the laboratory analyses were, of course, made on the preserved samples.

A check on possibilities of error in both field and laboratory technique showed that methods were comparable. The field tests were made in a steam bath at essentially the same temperatures as those used in the laboratory, and the same reagents were used in both places.

Dr. M. Starr Nichols, of the State Laboratory of Hygiene, showed that the chloroform was probably the cause of the discrepancy in results. A small portion of chloroform placed with potassium permanganate caused a decoloration of the permanganate in a few hours.

The authors took up the problem in the Sanitary Engineering Laboratory at the University of Wisconsin. The results of the experiments show that:

1. Ordinary chloroform, because of the presence of foreign ingredients, has an oxygen consumed value.
2. Ordinary chloroform used as a preservative for sewage and trade waste samples increases the oxygen consumed value. The increase is proportional to the amount of chloroform used.
3. Foreign ingredients (ethyl alcohol and perhaps other compounds) present in ordinary chloroform cause the increase in oxygen consumed values.
4. Heating of preserved samples prior to running the oxygen consumed test will not remove the oxygen consuming ingredients of the chloroform within the temperature limits through which it can be applied. If the temperature is raised sufficiently high to remove the impurities in the

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[1] Ordinary chloroform refers to U. S. P. (unwashed) chloroform.

chloroform, the organic matter in the sample may be changed so as to have a different oxygen consumed value.

5. These foreign ingredients can be removed by washing the ordinary chloroform with water. The chloroform thus washed has little or no oxygen consumed value.

6. Washed chloroform is at least as effective as a preservative as the unwashed.

Discussion of Results

The oxygen consumed values of ordinary chloroform were shown by placing known amounts of this preservative in distilled water, mixing well, allowing to settle and running the oxygen consumed test on the liquid. The oxygen consumed value was proportional to the amount of chloroform added per unit quantity of water as shown in Figure 1. Note that the value was about 35 p. p. m. for a sample containing 6 cc. per litre, the amount of the preservative recommended in Standard Methods (American Public Health Association). With 15 cc. of the preservative per litre of solution the oxygen consumed value was 90 p. p. m.

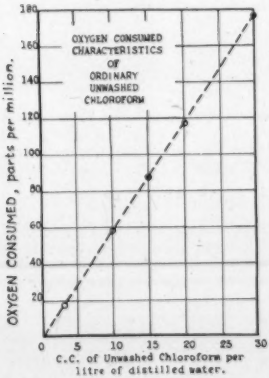

FIG. 1.—Oxygen Consumed Value of Ordinary Chloroform Mixed with Distilled Water

For some very strong wastes the error introduced in oxygen consumed values because of the oxygen consumed value of the ordinary chloroform used as a preservative may not be appreciable, particularly when the wastes are diluted before running the test; but for wastes of average concentration the percentage error would be large.

Tests run in the same manner using synthetic milk-waste (1 per cent solution of skim milk in tap water) and also sewage, indicate that the proportional effects of various amounts of ordinary chloroform may be different for different sewages and types of waste. It would be inadvisable, therefore, without definite information regarding a particular waste, to use the curve in Figure 1 to correct oxygen consumed values run on samples preserved with unwashed chloroform.

After the oxygen consuming characteristics of the chloroform were determined, a method was sought to eliminate the error introduced by the chloroform.

Heating of the sample to dispel the chloroform was tried, and it proved very successful with distilled water samples. The oxygen consumed value could be reduced to 6 or 8 p. p. m. by boiling the sample for a period of 3 to 4 minutes before running the test. (See Figure 2.) However, additional experiments run on milk waste indicated that these high temperatures had an appreciable effect on the oxygen consumed value of the waste itself, due to decomposition of the organic matter.

It was found that the chloroform could be relieved of its oxygen consuming characteristics by washing with water. The washing process

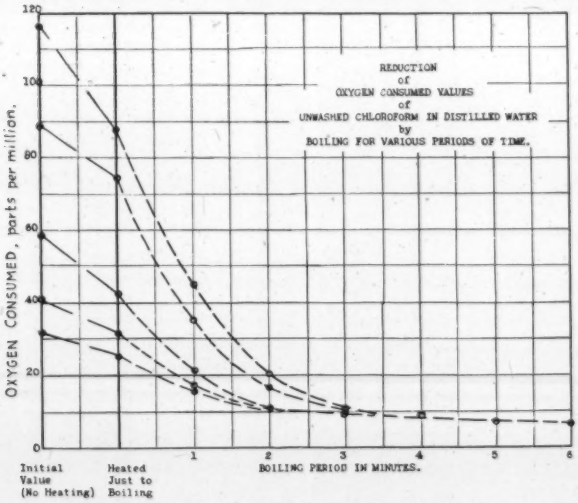

FIG. 2.—Effect of Boiling Chloroform in Distilled Water.

consisted of shaking the chloroform in water, and pouring off the supernatant water which contained the oxygen consuming impurities.

Tests run with this washed chloroform placed in distilled water indicated that oxygen consumed values were so low as to be inappreciable (2 to 3 p. p. m.), regardless of the proportion of chloroform added to the sample. Similar tests run on milk waste showed no appreciable increase in oxygen consumed values with various amounts of chloroform in the samples. (See Figure 3.)

It seemed reasonable that at least part of the impurities in the chloroform might be ethyl alcohol because of the use of alcohol in the manu-

facture and preservation of chloroform and because alcohol is readily oxidized by potassium permanganate.

Therefore, tests were made for alcohol. The iodoform test for alcohol was positive; crystals of iodoform were identified by microscopic study. Further proof of the presence of ethyl alcohol was obtained by the use of the ethyl-benzoate test. No attempt was made to determine what other impurities may be present.

Plate cultures were made of raw sewage and raw milk waste, and fo samples of both, preserved for 24 hours with 6 cc. per liter of both washed

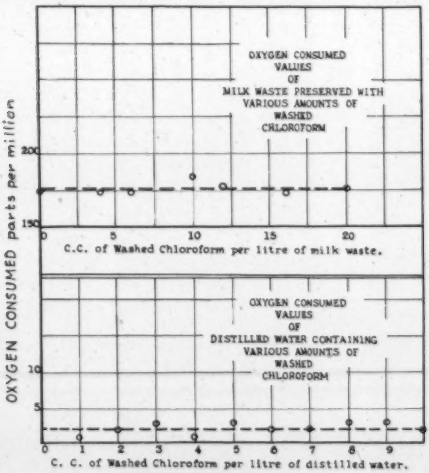

FIG. 3.—Oxygen Consumed Values of Washed Chloroform.

and unwashed chloroform. The plates with the waste preserved by washed chloroform showed markedly lower counts at the end of 48 hours of incubation at 37° C., than did the plates with waste preserved by unwashed chloroform. This was true for both the sewage and the milk-waste. Therefore, indications are that the washed chloroform is at least as good and perhaps better than the unwashed as a preservative.

The authors wish to acknowledge gratefully the helpful suggestions and coöperation of Dr. M. Starr Nichols of The Wisconsin State Laboratory of Hygiene.

Sewage Works Operation

About Activated Sludge

By F. R. O'Shaughnessy, A.R.C.Sc., F.I.C.[1]

The so-called activated sludge process consists, in my opinion, of the exploitation, under somewhat arbitrary conditions, of a highly special natural biophysical phenomenon, which is itself the product of highly special biochemical conditions which constantly recur in natural waters. I refer here to the "floc" of activated sludge, which may be regarded as the unit or microcosm of the process.

It is to the detailed studies which are being made in England and America of the self-purification taking place in polluted streams that I look for much of the information which is still wanted for the elucidation of the conditions which must be observed in the proper and economical handling of activated sludge when applied to the treatment of sewage. Careful discrimination will, of course, still be necessary in interpreting this information as it is forthcoming, and the success of the sewage expert in utilizing it will depend on his capacity for selecting and applying that which is significant and relevant.

If one considers the action in a sewage polluted stream one may find that in quiet pockets and backwaters there is an accumulation of polluting matter so that depletion of oxygen occurs and anaerobic action is dominant. Immediately following this in the region of slowly moving water usually come the various filamentous growths, which are capable of physically maintaining themselves in a moving environment rich in organic matter and low in oxygen content. There also, probably, the water is rich in plankton. Following this stage closely and often alongside it, but usually in shallower reaches of the stream where oxygen is more plentiful, we get the phenomenon to which I referred in my first paragraph, *viz.*, the deposition of a gelatinous film on the stones of the stream bed. This material may maintain itself in position in water moving at intermediate velocities, and so contribute materially to the self-purification of the stream, but it is a matter of common observation that at points of very high velocity growths cannot maintain themselves. The film on the particles of medium in a good trickling filter is similar to this material and fulfills a similar "rôle" but under controlled conditions; while

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the "floc" in activated sludge brings about similar changes under more artificial and therefore more limited conditions.

The use of what is commonly termed activated sludge for the purification of sewage by continuous agitation in the presence of air is, strictly speaking, quite an arbitrary procedure; and the justification for this procedure is the success which has attended its judicious and skillful use in numerous cases. But the not inconsiderable number of failures point inexorably to the fact that the task imposed on this technique from time to time exceeds the limitations of the procedure. A study of these limitations is quite as important as the study of the possibilities, if the character of the activated sludge process is to be understood. It is suggested here that the essential elements of the process reside in the floc; for through the medium of the floc the non-settling sludge-forming material in the sewage liquor is converted fairly quickly into a form which will settle readily (perhaps the chief outstanding merit of this process), and if the action is continued further, oxidation of the residual impurity in solution continues at a diminishing rate till stabilization point is reached, *i. e.*, till the rate of oxidation becomes negligible. For the purposes of the present article the following observations and considerations are put forward in order to elucidate the writer's way of looking at the matter.

The fact that the activated sludge process goes so well and easily when properly applied to a purely domestic sewage of moderate strength, and further that the stabilization point referred to above (*a*) can be attained with a reasonable expenditure of energy, and (*b*) coincides with a degree of purity which allows the discharge of the liquid in a condition which permits fish to live quite comfortably therein, is rather striking. As against this, if materials not normally present in domestic sewage (but which may occur in industrial sewages) are introduced, a point is reached very quickly when serious interference with the process occurs.

Anaerobic conditions tend to destroy this floc or film formation, and in a stream anaerobic conditions can only be maintained in quiet places where there is little or no movement. The floc or film, on the other hand, requires the presence of free dissolved oxygen in the water. The amount of oxygen is very small. It is therefore suggested that this floc formation is designed to provide a matrix upon which the organisms may sustain themselves in the presence of moving water, and that this natural phenomenon is the basis upon which the whole activated sludge process rests. Many workers have noted the fact, familiar by now, that the presence of protozoa is not at all essential to a good activated sludge.

May I now approach the matter from another standpoint. Those of us who are familiar with the production of activated sludge as a matter of routine in our work are familiar with the increase in the intensive action of the sludge as the flocs slowly take on their form. The difference, for

instance, in the rate of attack by an anaerobic ferment and by activated sludge is very great, the speed of the latter being very remarkable where the conditions are favorable. Under the microscope the anaerobic ferment presents a field swarming with independent organisms, whereas the activated sludge is dominated by the floc and if in good condition few independent bacteria are to be seen. Further, the evidence indicates that the organisms are not dissimilar, being derived from intestinal origin in both cases.

Thus it would appear that in the activated sludge the organisms have been swept up or "regimented" into the floc and thus their action has been intensified. Again attention might be directed to a very interesting table prepared by H. Wilson, B.Sc., of Reading (England) (*Proceedings Assoc. of Managers of Sewage Disposal Works*, 1927) showing rates of solution of oxygen when air was bubbled at standard rates through the following:

No. 1. Sewage adjusted to pH 4
No. 2. Sewage adjusted to pH 6
No. 3. Sewage alone pH 8
No. 4. Sewage adjusted to pH 9
No. 5. Sewage adjusted to pH 10
No. 6. Sewage plus activated sludge
No. 7. Distilled water boiled and cooled in closed vessel pH 7.6

In Nos. 1, 2, 4, 5 and 7 the curves were roughly similar, the quantity of dissolved oxygen rising rapidly, but in No. 6 the amount remained low (about 1.5 p. p. m.) for 3 hours and then slowly rose. But in No. 3, *viz.*, "sewage alone" the oxygen content rose fairly quickly at first, and after $2^1/_2$ to 3 hours fell rapidly. In the subsequent discussion of that paper I suggested that the latter observation was of great importance and represented the point at which flocculation had been initiated, with the result that the intensive attack on the organic matter, and therefore also the dissolved oxygen, had begun. This result had puzzled Wilson greatly and for this reason he had repeated the experiment many times, but always with the same result.

Experience indicates that the incidence of materials foreign to ordinary domestic sewage (industrial wastes, etc.) is greatly modified by dilution, and problems which loom large in England with the moderate water consumption of 25 to 30 gallons or so per head either never arise or are greatly diminished by the much larger volumes of water used in America.

Whilst the evidence steadily accumulating indicates that the amount of oxygen (or rate of aeration) necessary to maintain the floc and therefore the sludge when treating a domestic sewage or an industrial sewage containing oxygen carriers (which undoubtedly protect the floc) is low, the

amount of energy necessary to keep the sludge in circulation is very considerable. In this connection may I point out that experiments were carried out by me several years ago, since referred to on various occasions, which indicated that the relationship between the power necessary for aeration as against the power necessary for circulation or mixing was of the order 1:10 or even less. The suggestion at that time was that by separating the two operations economy might be looked for and the results obtained by Kessener in Holland Imhoff at Essen-Rellinghausen and Makepeace at Hanley (England) confirm that view.

Partial Purification

The departure made at Birmingham as a result of investigations made by me, *viz.*, to apply the activated sludge technique to the settled sewage at Birmingham, has for its object the modification of the sewage liquor in order to make it more suitable for application to the bacteria bed. It will be seen that this departure follows logically on the lines of thinking indicated earlier in this article, and a number of independent workers both here and in America have confirmed the soundness of this procedure.

Recently there has been manifested a tendency here and elsewhere to resort to what is described as a "multi-stage" division of the operations, one engineer treating of the matter as if it were almost a pastime.

As against this, I pointed out that for any such proposal there must be a clear and definite advantage such as elimination of nuisance or greater economy, and indeed from a biochemical point of view considerable discretion must be used in even applying one-stage partial purification. For instance, the material flocculated is usually highly nitrogenous, and care is needed in the case of a sewage containing much carbohydrate to see that the biochemical nitrogen-carbon ratio is not unduly disturbed. It is quite easy to do this if the proper procedure is adopted.

May I conclude by alluding to a most interesting problem to which I have given attention recently, *viz.*, the case of a sewage or other nitrogenous material containing sugar. This kind of problem illustrates very well the important principle, *viz.*, that the object of the chemist in these matters is "to direct the course of the biochemical change." It is hardly necessary to point out that such material, if uncontrolled, is likely to develop strongly acidic bodies of a very nauseous character; but by imposing certain conditions on the fresh material, a non-nauseous alcoholic fermentation can be set up, the colloidal solids may be flocculated, and the results so far indicate that the subsequent aeration stage is much facilitated by this preliminary treatment together with subsequent procedure which shall conserve the nitrogen in the biochemical system.

Still another important and useful question relates to the presence of various kinds of protozoa in activated sludge. I do not refer to the de-

batable question of the "rôle" of these organisms, for it is generally agreed that we can get on very well without them. Rather do I refer to their significance. To take examples, one usually finds that saccharine materials in a sewage will bring about the development in considerable numbers of groups of protozoa not found in activated sludge when such materials are absent. Again if the pH value is varied certain types may be able to flourish best under certain values while others fail, and still further a restricted oxygen supply will encourage one type and a generous oxygen supply will encourage others.

Thus the study of these conditions with a careful record of the forms appearing may be capable of furnishing qualitative results which might prove extremely useful.

Addendum

The paper on "The Treatment of Sewage by Stream-Flow Aeration" by Harry N. Jenks and Max Levine in Reprint No. 1248, U. S. Public Health Reports, furnishes evidence and considerations which are opposite to the arguments in this article.

With their main argument I am in whole hearted agreement, *viz.*, "all so-called artificial treatment processes are simply adaptations of those found in Nature."

They indicate some of the disadvantages of the activated sludge technique but do not stress its outstanding merit, while they emphasize the advantages of the trickling filter but do not emphasize its principal limitation.

Briefly it may be said that sewage contains sludge-forming material not in solution and other material which is in true solution. Of the sludge-forming material 70 per cent to 80 per cent is readily settled out in a plain sedimentation tank. The settled sewage then contains non-settling colloidal matter which may choke the trickling filter, but which may be flocculated very rapidly by the activated sludge. It also contains material which may be dealt with only slowly by the expensive activated sludge technique, but which is dealt with easily, rapidly and therefore economically on the bacteria bed.

Whilst making the fullest acknowledgment of the merits of their arguments for "stage" treatment, especially for special industrial wastes such as milk, etc., it may be pointed out that their very lucid presentation of the case, together with the points I raise above, make the combination of activated sludge followed by bacteria bed an eminently sound and logical procedure. One point, and an important one which has already been indicated and needs to be stressed, is the biochemical balance which must be maintained in order to produce economical and satisfactory results in the application of this procedure.

The Use of Single and Multiple-Unit Tank Cars of Liquefied Chlorine Gas in Disinfecting Sewage

BY JOSEPH W. ELLMS[1] AND G. T. POND[2]

Two of the three sewage treatment plants of Cleveland, Ohio, are located on the shore of Lake Erie. Disinfection of the effluents with chlorine is practiced throughout the bathing season, during the months of June, July and August of each year. The westerly plant is provided with two sets of bar gratings, grit chambers and Imhoff settling tanks. The effluent from this plant is discharged into the lake through an outfall sewer about 2500 feet in length. The easterly plant has only a double set of bar gratings and grit chambers. Its effluent is also discharged into the lake through an outfall sewer 2500 feet long.

The effluent from each plant is measured through venturi meters which are located in buildings known as the disinfection buildings. The flow at the westerly plant will average about 30 million gallons daily, and at the easterly plant about 90 million gallons daily. The maximum daily flow at both plants will exceed the average rate of flow by 30 to 35 per cent, while flood flows will be at still higher rates.

The disinfection building at the westerly plant was originally equipped with six Wallace and Tiernan vacuum type chlorinators, five of which had each a nominal daily capacity of 720 lb. of chlorine and one of the variable feed type with a capacity of 360 lb. per day. The easterly plant was provided with eighteen chlorinators of the same type as at the westerly plant, seventeen of them having each a capacity of 720 lb. daily, and one of the variable feed type with a capacity of 360 lb. per day. The variable feed types of chlorinators at each plant were removed a number of years ago, leaving only the fixed feed type of machines.

The chlorine from these machines was discharged in each case through a manifold into the sewage in an open chamber just beyond the venturi meters. From this small chamber or manhole the sewage passed directly into the outfall sewer. The last one thousand feet of this sewer is a tapered section perforated with holes to permit of the diffusion of the sewage in the lake water. The depth of water along this section is about 30 feet.

Both plants were originally designed and equipped to draw their supply of chlorine from cylinders containing 150 lb. of the liquefied gas. A battery of these cylinders was placed in a long wooden trough through which warm water was circulated by small electric motor driven centrifugal pumps. The warm water was obtained from gas-fired heaters placed in the water circulation system. The cylinders were connected through

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[2] *Chemist-in-Charge, Easterly and Westerly Sewage Disposal Plants, Dept. Public Utilities, Cleveland, O.*

a manifold to the gas supply pipes of the chlorinators. Gas only was drawn from the tanks, since the latter acted virtually as evaporators for the liquid chlorine which they contained.

The large volumes of sewage to be treated each year, the high chlorine dosage required to produce efficient results and the great number of small cylinders handled during the three months disinfection was practiced, made it desirable to purchase the chlorine in larger containers and to equip the plants with evaporators of sufficient capacity. These plants used from 1925 to 1928, inclusive, approximately 600,000 to 800,000 pounds of chlorine each year. This meant the handling of about 5000 cylinders of chlorine each year within a period of three months.

The desirability of being able to purchase chlorine at a lower price, if bought in single or multiple-unit tank cars, was fully appreciated for several years prior to the change in equipment for the season of 1929. Money to make the necessary changes was made available in 1929. The apparatus designed and equipment installed are described in the following paragraphs of this paper.

The easterly plant, which uses the most chlorine, is unfortunately so located that it cannot be reached by a railroad. Consequently, multiple-unit tank cars consisting of fifteen one-ton containers were set on the private railroad siding of a manufacturing plant located about one mile from the sewage plant. The tanks were unloaded from the cars to a city owned truck with a crane provided by this company, and empty containers were reloaded on the car with the same crane. The truck loaded each time with three full cylinders conveyed them to the sewage plant. They were unloaded there by means of a 2-ton electrically driven hoist mounted on a trolley rail and pushed by hand into a storage shed adjacent to the disinfection building. Floor space for the storage of three carloads (45 one-ton cylinders) was provided in this building.

The unloading of a multiple-unit tank car of 15 one-ton cylinders to a truck, transporting the cylinders in the truck to the sewage plant, unloading them with the hoist at the storage shed, reloading the truck with empty cylinders, returning with them to the car and reloading them on the car required on an average about four hours.

The trolley rail from which the hoist was suspended was so arranged that the cylinders taken from the truck at the unloading door near the center of one side of the building could be placed on rails laid on the floor on both sides of the shed, and along which the cylinders could be rolled by hand to either end of the building. The trolley rail divided into two right-angled branches on the side of the building opposite the unloading door, either branch being connected as desired by a switch to the main line. These branches permitted twelve cylinders to be placed in a row on cradles and in front of a pipe manifold.

The liquid chlorine valve of each container was connected to the one-inch copper tubing manifold by means of a 1/4-in. flexible copper tube and a 3/4-in. chlorine manifold valve. Figure 1 shows the lifting bail for the ton containers and the manner of handling them with the hoist.

FIG. 1.—Lifting Bail for Chlorine Containers.

The pressure of the gas above the liquid chlorine in the containers was always sufficient to force the liquid to the evaporator. The evaporator consists of a one-ton chlorine cylinder. This cylinder is 80 in. long, 30 in. in diameter and weighs empty 1300 pounds. It is placed within a

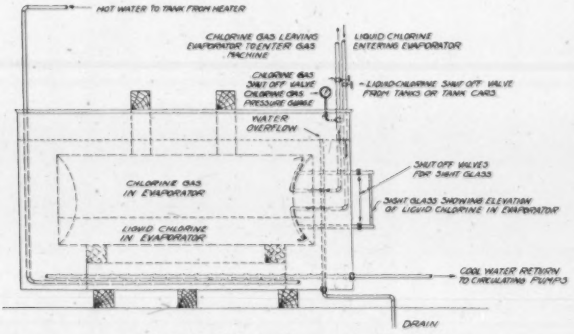
HOT WATER TO TANK FROM HEATER
CHLORINE GAS LEAVING EVAPORATOR TO ENTER GAS MACHINE
LIQUID CHLORINE ENTERING EVAPORATOR
CHLORINE GAS SHUT OFF VALVE
CHLORINE GAS PRESSURE GUAGE
LIQUID CHLORINE SHUT OFF VALVE FROM TANKS OR TANK CARS.
WATER OVERFLOW
SHUT OFF VALVES FOR SIGHT GLASS
CHLORINE GAS IN EVAPORATOR
SIGHT GLASS SHOWING ELEVATION OF LIQUID CHLORINE IN EVAPORATOR
LIQUID CHLORINE IN EVAPORATOR
COOL WATER RETURN TO CIRCULATING PUMPS
DRAIN

FIG. 2.—Chlorine Evaporator Tank.

steel tank 8 ft. 8 in. long, 4 ft. wide and 5 ft. high through which warm water from the heater is circulated. The chlorine gas produced by the evaporation of the liquid chlorine is drawn directly from the top of the evaporator to the chlorinating machines. The heater is an ordinary

instantaneous gas-fired water heater with thermostatic control. The centrifugal circulating pumps are in duplicate. Temperature regulation of the water was found to be easily controlled, and the cost of heating low.

Figure 2 shows in detail the evaporator tank within the steel tank. The evaporator rests upon a wooden cradle, and is held down by posts spiked to cross beams which are bolted to the top of the steel tank in order to prevent the displacement of the evaporator when submerged in the water used in filling the steel tank. The liquid chlorine supply pipe is connected to the opening in the evaporator formerly used for drawing the liquefied gas, and the gas delivery pipe to the former gas valve opening. On the gas line supplying the chlorinators is a pressure gage. A sight glass tube connected into the top and bottom of the evaporator permits the level of the liquid chlorine in the evaporator to be under constant observation.

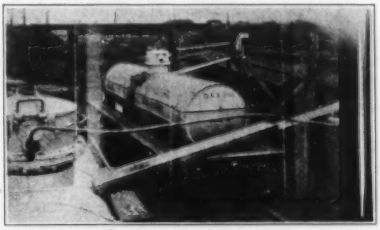

FIG. 3.—Fifteen-Ton Chlorine Tank Cars at Westerly Plant.

The water circulation pipes are also shown. The warm water is discharged through a perforated pipe which lies on the bottom and at the center of the steel tank directly under the evaporator. The cool water is drawn off at the side and bottom of the steel tank through a perforated pipe. An overflow pipe connected to a drain is also provided.

At the westerly sewage plant a railroad siding adjacent to the plant made it possible to employ 15-ton single tank cars of chlorine as a source of supply. A second spur track siding was built so that a second car of chlorine could be placed upon it and be available when the first was empty, thus avoiding any interruptions in the treatment of the sewage. In Figure 3 may be seen the tank cars standing on the railroad sidings and the manner in which they were connected to the main supply pipe line.

Liquid chlorine from the tank cars was conveyed through a pipe line a distance of about 350 ft. to the evaporator located in the disinfection

building. This evaporator was of the same type as that used at the easterly plant. In Figure 4 may be seen the steel tank water bath which contains the evaporator and near it the hot water heater and circulating pumps.

The piping used to convey the liquid chlorine to the evaporator was laid in a box 5 in. square in cross section. The top of the box was set flush with the surface of the ground in order to have the pipe easily ac-

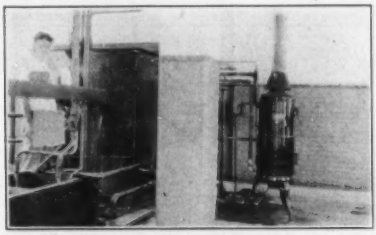

FIG. 4.—Evaporator Tank and Water Heater at Westerly Plant.

cessible. All of the pipe used to convey liquid chlorine to the evaporators at both plants was 1-in. copper tubing connected by means of Parker Appliance Co.'s fittings (Figure 5). These joints are easily made and will withstand high pressures. Iron piping could have been used at a somewhat less cost. Experience with several different types of valves indicated that in order to prevent leakage around the glands and to avoid

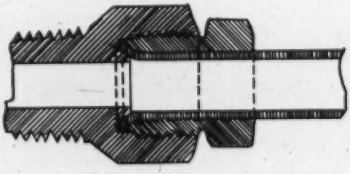

FIG. 5.—Special Tube Coupling for Chlorine.

sticking and corroding of the valve stems, none was satisfactory except those made especially for controlling the flow of chlorine either as a liquid or as a gas. Gages must also be especially designed for chlorine.

Since the hazard involved in handling large volumes of chlorine gas is unavoidable, protective measures for the operators should always be provided. At both plants water pipe with hose attached is conveniently

placed so that flooding of leaking pipes or valves may be effected if dangerous conditions should arise. Gas masks are also always available for the use of attendants in order to enable them to close valves in an emergency.

With the above-described equipment, there were applied during a period of 84 days at the easterly plant, 510,000 pounds of chlorine, and at the westerly plant, in 85 days, 223,400 pounds of chlorine. This was equivalent to applying on an average 66.89 lb. of chlorine to each million gallons of sewage passing through the easterly plant, and 76.46 lb. of chlorine per million gallons of sewage flowing through the westerly plant.

At the contract price for chlorine in 150-lb. cylinders, the chlorine used at the two sewage plants would have cost nearly $15,000 more than it did cost in single- and multiple-unit tank cars. Since the new equipment for both material and labor cost approximately $8500, the saving for the first year alone was practically $6500, and for future years will be probably more than double this sum.

A comparison of the unit costs for disinfecting sewage at both plants for the two years 1927 and 1928, when chlorine was bought in 150-lb. cylinders, with those for the year 1929, when the chlorine was purchased in single and multiple-unit tank cars, is shown in the following table.

AVERAGE COSTS PER MILLION GALLONS FOR DISINFECTING SEWAGE DURING THE YEARS 1927, 1928 AND 1929

Year	Chlorine Purchased in	Easterly Plant	Westerly Plant
1927	150-lb. cylinders	$4.03	$5.95
1928	150-lb. cylinders	4.56	5.64
1929	Multiple-unit and single 15-ton tank cars	2.48	3.08

The ample capacity of the evaporators, the easier control of the flow of gas and the greatly reduced labor required have convinced the writers of the advantages of the changes which were made at the two sewage plants. Where large volumes of sewage are being treated, the employment of large containers should commend itself to operators aside from the much lower cost at which disinfection may be affected.

Acknowledgment is due to J. A. Dannley, assistant engineer of the Division of Water, for the preparation of drawings accompanying this paper.

The Sewage Disposal Problem in the Passaic Valley[1]

BY J. RALPH VAN DUYNE[2]

The Passaic Valley Sewerage District, as established by the laws of 1902, embraces an area 18 miles long and 4½ miles wide along both sides of the Passaic river from Paterson to Newark. This area containing approximately 80 sq. miles includes 22 municipalities with a present population of over 1,000,000.

Forty years ago the steadily increasing population and industrial development in this district caused the river to change rapidly from a pure, wholesome stream to a foul open sewer serving only to carry away the wastes of the district.

In 1902, public sentiment forced the passage of legislation for sanitary control of the river and the abatement of its pollution.

Ten years elapsed before actual construction of the Passaic Valley System was started in the spring of 1912, and it was not until August, 1924, that this $21,000,000 project was completed and put into actual operation.

The system consists of a main intercepting sewer 22 miles long ranging from 4 to 12 ft. 6 in. in diameter, 14 miles of branch intercepting sewers ranging from 1 to 5 ft. in diameter, three pumping stations and sedimentation basins.

At the southerly extremity of the main intercepting sewer on the Newark Meadows, the sewage is lifted 43 feet into plain sedimentation basins designed with an hour and a half detention. From these basins the effluent flows through a five mile pressure tunnel under Newark Bay, Jersey City, and New York Bay, where it is discharged off Robbins Reef in the deep waters of the ship channel 2 miles below the Statue of Liberty (Figure 1).

The cost of maintaining and operating the Passaic Valley Sewerage System is borne by the twenty-two participating municipalities in direct proportion to the quantity of sewage discharged by each municipality. To determine these individual flows, measuring devices have been constructed at the boundaries of the various municipalities. Where the discharge is comparatively small, these measuring devices have taken the form of weir chambers which contain accurately cut, sharp-crested weir plates of various types, adapted to the condition of flow at their particular locations and equipped with suitable recording apparatus. There are 25 of these weir chambers in the system.

Where the flow is comparatively large, the measuring device has taken the form of a venturi meter inserted in the line of the intercepting sewer with by-pass conduit, suitable recording apparatus and inlet and outlet

[1] *Presented at a Meeting of the New York State Sewage Works Association, New York City, Jan. 18, 1930.*

[2] *Chief Engineer, Passaic Valley Sewerage Commission.*

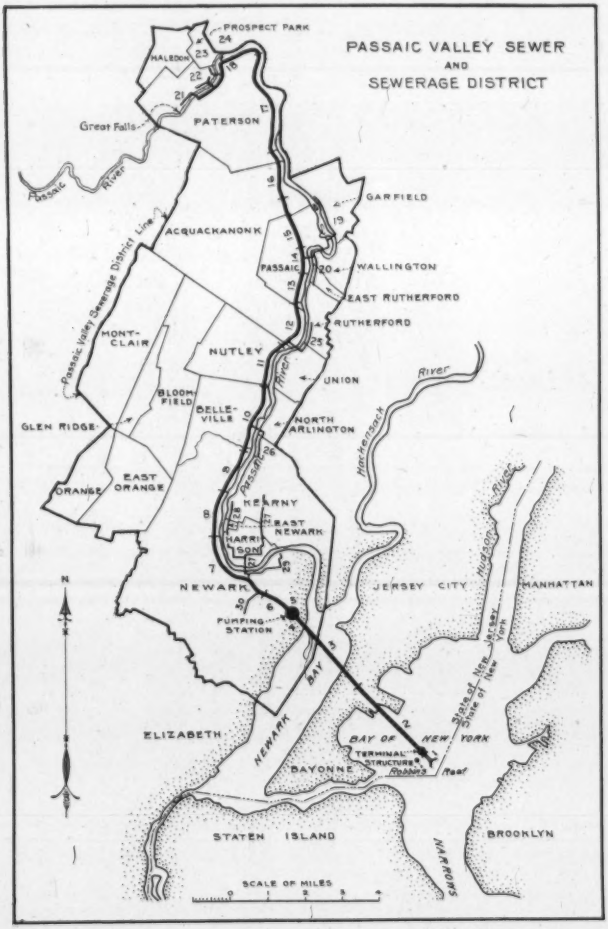

FIG. 1.—Outline Map of Sewerage District and Intercepting Sewers.

chambers, all built under the surface of the street with manholes for entrance and for cleaning purposes. There are ten venturi meters installed in the system. A meter gang composed of 4 men with an automobile for transportation devotes its entire time to the care of these measuring devices.

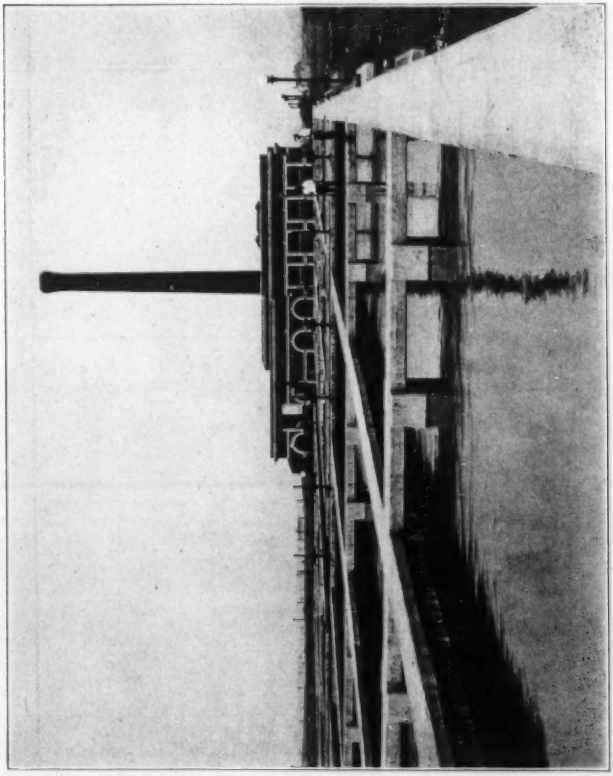

FIG. 2.—Sedimentation Basins (Newark Bay Pumping Station in Background).

The necessity for metering all of these flows has a very material effect on the cost of operating the system. In front of every weir and venturi meter there is installed a grit well and a screen to prevent fouling of the weirs and clogging of the venturis. In most instances these have to be

cleaned every day, requiring two gangs of six men and 2 foremen to maintain. An automobile is furnished to each gang for transportation. If the necessity of metering could be eliminated, all this cleaning of screens and grit wells could be accomplished at the main pumping station on the Newark Meadows when the entire flow of the district passes

FIG. 3.—Map Showing Location of Sewage Diffusion Area and Sludge Dumping Grounds.

through a large grit chamber, which is cleaned by a locomotive crane, and then passes through electrically operated fine cage bar screens before entering the pumps, which lift the sewage into the sedimentation basins (Figure 2).

During the five and one-half years that the system has been in operation the average daily flow has increased from 100 to 143 m. g. d. and the

sludge removal from the sedimentation basins has increased from 4.7 tons of 90 per cent sludge per million gallons of sewage to 8.0 tons of 90 per cent sludge per million gallons.

The cost of barging this sludge to sea, which is done under yearly contract, has steadily declined until at the present time it amounts to 24.4 cents per ton. Recent exhaustive studies of the advisability of owning and operating our own sludge boats have indicated that as long as this work can be accomplished under contract at the present price it is by far the most economical method. The total trip from our bulkhead at Newark Bay, at which the point sludge boat is loaded, to the dumping grounds and return is 60 miles (Figure 3).

At the present time practically the entire sanitary sewage waste of the district is being discharged in the Passaic Valley system, also a large percentage of the polluting trade waste.

The total cost of operating the Passaic Valley system during 1929 was $790,000 which, on the basis of sewage flow, represents a cost of $15.06 per million gallons of sewage discharged.

The total maintenance organization including the engineering staff numbers about 150 men.

Sewage Works Extensions, Dagenham.—The urban district of Dagenham, with a population of 100,000, lies some distance above London on the Thames. It is the site of large industries, including the British Ford plant, which will employ 15,000 workers. The present sedimentation tanks have a capacity of only 1 m. g. d. and must be expanded to treat 5 m. g. d. in the near future. The Port of London authority, concerned about the growing pollution of the Thames, quoted a standard for the effluent of 2–3 p. p. m. albuminoid ammonia. Sedimentation would be insufficient to meet this standard.

After studies of proposed extensions, including a review of recent German developments, the district engineer, Mr. T. P. Francis, decided to install a 1.0 m. g. d. semi-experimental unit, consisting of detritus tanks with Simplex screens; a sedimentation tank similar to that installed by Prüss at Essen-Nord; a 1.0 m. g. d. Simplex aeration unit of 14 tanks, 6 for aeration of sewage and sludge for 4.8 hours, and 8 for reaeration of sludge for 20 hours; final settling tanks and a battery of Prüss type digestion tanks. All aeration tanks can be used for partial treatment of 3.0 m. g. d., in which case a diffused-air unit may be installed for reaeration of sludge. All sludge is to be digested in the separate digestion tanks.—*The Surveyor*, **77**, 251–254, Feb. 14, 1930.

Industrial Wastes Problem in the Passaic Valley[1]

BY WM. GAVIN TAYLOR[2]

Prior to August, 1924, the city of Newark and its satellite cities, including Paterson and Passaic with their respective groups of industrial communities, discharged all sewage and industrial wastes into the waters of the Passaic River. The lower portion of the Passaic River from Newark Bay to the city of Passaic, a distance of about twelve miles, is a tidal estuary, while above the city of Passaic the river carries the drainage of 950 square miles. Dry weather run-off, however, is not that of a normal natural stream having a like drainage area, because of the numerous water supply developments, which include the extensive storage reservoirs of the Newark, Pequannock supply and the twenty-eight billion gallon reservoir of the new Wanaque water supply project. Naturally, these water supply developments restrict the dry weather run-off to the point of utter disappearance. For weeks at a time, during even normal summer seasons, no water flows over the diversion dam in Paterson, and the "Great Falls" of the Passaic remain dry.

The burden placed upon the river, before the opening of the Passaic Valley Sewer System in 1924, was so severe that habitation adjacent to the river banks was almost impossible. The river waters were black and putrid, nauseating odors arose, and hydrogen sulphide was destructive to lead paints half a mile distant. The river deserved, perhaps, the characterization of Woodrow Wilson when he said that "its waters were too thick to flow and yet too thin to plow." This condition of the Passaic River has now passed, and the pollution which menaced the development of this prosperous metropolitan area encompassing a population approaching a million and a quarter, is not to return.

Legislative enactment in 1907 created the Passaic Valley Sewerage Commissioners, a corporate body constituted to act in a dual capacity: as an arm of the state, with dominion over the river, to prevent the pollution of the waters; and as an agent, representing a voluntary association of municipalities, in the construction and operation of a metropolitan sewerage system serving the communities contiguous to the river. Under the leadership of the commissioners, twenty-two municipalities have, through a system of inter-municipal contracts, undertaken and completed sewerage works involving a total capital investment of over $22,000,000. Under the original contract, executed in 1911, and its supplements, construction work was begun in 1912 and completed and put into operation in 1924.

[1] *Presented at a Meeting of the New York State Sewage Works Association, New York City, Jan. 18, 1930.*

[2] *Consulting Engineer, Newark, New Jersey.*

Industries in Passaic Valley

Within the area served by the Passaic Valley system there are concentrated the most important manufacturing and residential centers of the state, the district forming an important sector of the metropolitan area of "Greatest" New York. The range of industries is extensive: in Newark, with its population of half a million, the industries are highly diversified and range from the manufacture of doll's voices to that of steel ships; Passaic is a center for woolen and other textile industries; and Paterson is the focal center of the United States for the manufacture and dyeing of silk.

At the time the enabling acts of the legislature were passed, 1903 and 1907, the volume of trade wastes generated in the district did not constitute the vast proportion of the total flow which it does now. This change in proportion is due to many causes arising from changes in style and type of wearing apparel, general substitution of silks and more recently of rayon goods for cottons and woolens, radical changes in the processes of manufacture and other causes.

Volume of Industrial Wastes Intercepted

The basic law of 1907 contemplated that in the design of the trunk sewers consideration should be given to the interception of not more than ten per cent of the total of the trade wastes. This restriction could apply at that time to the district as a whole with its eighty square miles of territory, and could apply to each of the individual participating cities, excepting possibly Paterson, but it could not apply at the present time in several of the municipalities. Fundamental differences in processes have come into general use, particularly in the silk dyeing industry. Formerly, silk dyeing was done in skeins before weaving, now it is done principally in "pieces" after weaving. New and better processes have been developed for the manufacturer but they have also produced a greatly increased volume of trade waste. The weighting of silk, involving the deposit of tin in and upon the silk fibres, has become a general practice within recent years. The "weighting" gives body to the fabric and enhances the draping qualities, but it effects a profound increase in water consumption and volume of industrial waste discharged. Fortunately these tin-waste waters are clean and need not be discharged into the sewerage system in cases where the industrial plants are adjacent to the river or are tributary to an adequate storm water drain.

The statutory limitation with regard to ten per cent of trade-waste volume does not injure or limit the action of the contracting municipalities. Each municipality has its discharge allotment in the working capacity of the sewerage works and up to these limiting capacities the municipali-

ties have full jurisdiction. Allocations for total limiting sewage flows were made in 1910, at the time of the general design of the Passaic Valley sewerage project, and these sewage flows were estimated for a period of thirty years, that is, until 1940. In general, the capacities allocated will prove adequate up to and beyond that time. However, in certain industrial cities, Paterson and Garfield, where the volume of trade wastes has been multiplied many times by radical changes in industrial processes unforeseen in 1910, allocations of capacity are insufficient to meet the present-day industrial sewage discharge. The peak flows in certain of the cities today exceed their proprietary rights. The industrial growth of these cities is faster than the average of the district and major problems face them. Serious study was made by Paterson in 1924 and numerous important factors were outlined and promoted. Passaic also conducted an industrial-waste investigation with a view to effecting a reduction in the total trade waste discharged into the sewers. However, the cities were unable to finance construction adequate to handle these wastes. From 1925 to 1927, when an effort was made in this direction, the changes in industrial processes involving greatly increased water supply were so rapid that the industrial-waste situation, especially in Paterson, became more acute each succeeding year. During these three years, the total quantity of water delivered to consumers from all sources more than doubled, which is a vital factor when a city having 140,000 inhabitants is concerned. Parallel with the inordinate increase in the total volume of sewage and industrial waste discharged by these industrial cities, operating expenses for the intercepting system have risen until, in the case of Paterson, the cost for the current year is $276,000 or about $2.00 per capita. This is a substantial taxable burden and would seem to be of such importance as to warrant deep study. No easy answer is to be found in this case, and the problem must be considered from many angles.

Effect of Peak Flow

During the mid-day period of industrial work days, the peak flows at times approach the physical capacity of the main intercepting sewer and of some of the principal branch sewers. The ratios of daily flow from maximum to minimum are extraordinary in some cases. At one point the minimum rate during the night period is as low as 5.0 million gallons while the mid-day peak flow rises to approach a rate of 45 million gallons, a ratio of 900 per cent increase. The industrial peak flow rises sharply during the morning hours and descends with similar abruptness in late afternoon.

In diagrammatic form the daily industrial flow may be likened to the silhouette of the Matterhorn. This intense concentration of discharge of industrial wastes, as at Paterson, is a function of the silk dyeing industry.

Dumping occurs generally at eleven and four and this causes the summits in peak loads which normally occur at noon and at five o'clock. The sewer control problem, in such cases as this, may be likened to a traffic or transportation problem. The main sewers are entirely adequate for the average daily flow of sewage and trade wastes. The peak flows are the only real cause for concern.

Treatment of Industrial Wastes

Local treatment of industrial wastes at the point of origin is, in general, impossible and entirely impracticable throughout the Passaic Valley. The district is so densely populated, land values are so high and the character of the trade wastes is so concentrated that treatment by individual industries is not economically practicable. Treatment of trade wastes by each industry, with discharge of the effluents into the river and discharge into the sewers of the domestic sewage and a small fraction of the most concentrated trade wastes, as has been frequently proposed, is not the practicable or the economic solution of the critical situation which confronts the upper portion of the Passaic Valley. The trade wastes cannot be successfully treated in retail quantities at each industrial plant, for the reasons cited, but the entire volume from the district can be successfully and economically treated in wholesale quantities, by the district acting as a unit, with advantage to every community and every industry and at a cost which may be borne without a burden.

Additional Interceptors Needed

The final solution of the trade-waste problem in the Upper Passaic Valley lies in the construction, as soon as possible, of an additional system of intercepting sewers. That particular construction which is now most critically needed may be called the East Side Interceptor. This may be designed to relieve the acute pressure exerted upon Paterson, Garfield and adjacent communities. Prior to the construction of this supplementary intercepting sewer the need of additional sewerage construction by Passaic and other communities will be felt.

In the meantime, since completion of these additional interceptors cannot normally be accomplished within a five-year period under the existing contractual technicalities, the problem to be solved is that of making the most efficient use of the existing facilities. The peak flows are intense and whatever can be done to reduce them or to bring about an equalization of the sewage flow will be highly beneficial. To illustrate, take the traffic problem of peak loads on street car and bus transportation; it may be that a stagger system of working hours within certain districts would be practicable as one means of flattening the sewage flow curve.

Separation of Industrial Wastes

The Passaic Valley sewer law prohibits the discharge of "sewage or other polluting matter" into the river. Inorganic and non-putrescible dye wastes, even the light tinted spent dye and wash waters, are classed as polluting matter. This is undoubtedly a wise policy and the only one which can hope to restore the river to a wholly acceptable condition. Yet this factor is the crux of the problem, for if non-putrescible but faintly tinted dye and wash waters were not banned for river discharge there would at this time be no trade-waste burden in the Passaic Valley district. Decolorization has not as yet been made practicable at a cost within economic limits. This may be possible at some future date and the subject opens a wide field for research.

A complete separation of drainage systems within the industrial plants of the type prevalent in the upper Passaic Valley is the first essential in an effort to reduce the discharge into the sewers. There should be a dual system: One to receive the sewage and the polluting trade wastes; the other to receive boiler waters, condenser wastes, surface drainage and all non-polluted wash and other trade-waste waters, including tin-pit discharges; the polluted waters to be discharged into the Passaic Valley sewer for general treatment and the non-polluting waters to be discharged directly into the river. Such a program calls for an extensive system of storm-water and industrial sewers to serve such cities as Paterson, Passaic and Garfield, where the industrial establishments are located throughout the city area without thought of easy drainage or treatment of the trade-waste discharges.

Solution of Problem

The Passaic Valley trade-waste problem is very complex. The best and most desirable solution of this immensely important economic problem for the district as a whole, for separate communities and for individual industries, lies in the extension and enlargement of the Passaic Valley Sewerage System, that it may keep pace with the growth of the metropolitan area of New Jersey, whose growth is at least paralleling the growth of Greater New York. The industries of the Passaic Valley constitute the foundation of the prosperity of the district, and the wisdom of the official administration dictates the development of the water supply with the complementary sewerage facilities to whatever extent may be required to foster progressive development in this metropolitan area. In fact, until the requisite extensions and enlargements of the Passaic Valley Sewerage project are a reality, the trade-waste problem centers about the equalization of the daily flow, and the strict segregation of the non-polluting and the polluting waters, with the diversion of the former into the river and latter into the sewer.

Industrial Wastes and Stream Pollution

Dissolved Oxygen Conditions in the Harbor Waters of the Metropolitan District[1]

By William T. Carpenter[2]

The records of the dissolved oxygen content of the waters of New York Harbor are believed to be unique in their length. With the exception of 1910, there is no year since 1908 without its set of dissolved oxygen figures.

The work was begun under the Metropolitan Sewerage Commission and continued by it until the completion of the work in 1914. The Sewer Plan Commission then took it up, continuing it through 1915 and 1916. The Office of the Chief Engineer, Board of Estimate and Apportionment has carried it forward to date, so that there are available the records of the condition of the oxygen in New York Harbor water during twenty summers.

The purpose of the oxygen survey is to inform the sanitary authorities of the city as to the progress of sewage pollution in the main bodies of water comprising the harbor. For the use of the dissolved oxygen test as an index of pollution we are indebted to Dr. George A. Soper, Chairman of the Metropolitan Sewerage Commission during its existence. Dr. Soper suggested it to the Commission and did extensive research toward making it a practical routine tool of investigation. Like any single test, it has its limitations. For example, one could not recommend a given water for bathing merely because it is nearly saturated with oxygen, although, on the contrary, a water nearly devoid of oxygen would certainly be unsafe for bathing. The dissolved oxygen test is an excellent means of judging whether a body of water can take care of more sewage without nuisance or whether it is verging on nuisance conditions.

Sampling and Analyses

The territory covered by the survey extends along the Hudson River from its mouth to a point opposite Mount St. Vincent Academy, along the East River throughout its length, Long Island Sound to City Island, the length of the Harlem River, Upper and Lower New York Bay, Arthur Kill, Kill van Kull and Jamaica Bay. There are 31 regular stations which

[1] *Presented at a Meeting of the New York State Sewage Works Association, January 18, 1930.*

[2] *Chemist, Board of Estimate and Apportionment, New York City.*

are visited usually five or six times during the season from June 1st to October 1st. In addition there are several stations selected for study of special problems.

The work is conducted from a gasoline boat, about forty feet over all, manned by a boatman and a deckhand. The technical portion of the crew consists normally of a chemist and a sampler, though at times the deckhand performs the duties of the sampler in addition to his own. Complete equipment is carried on the boat so that the analysis is made immediately. The tests which are necessary for complete data include salinity of water, determined by a special hydrometer, temperature and dissolved oxygen in parts per million. With the aid of the auxiliary data (salinity and temperature) the percentage saturation can be computed. This computation, together with making a neat copy of the field notes, is performed in the office in days when no field work is in progress.

Tidal Variations

We have learned from this twenty years of work, and from tabulation of the results of analysis of over 10,000 samples, that there are three types of variation in the amount of oxygen present at any point in the harbor.

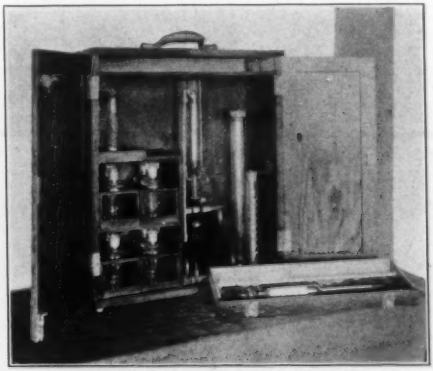

Fig. 1.—Portable Dissolved Oxygen Kit Used by the Board of Estimate and Apportionment, New York City.

First, there is variation with the state of the tide. The tidal phenomena of New York Harbor are extremely complex and until one acquires something of the marine pilot's lore, the changes of oxygen content with change

of tide appear to be without rhyme or reason. With a little experience, however, the results to be expected at the various stages are subject to fairly reliable prediction. In the lower portions of the harbor, the low oxygen figures are found near the end of the ebb current, and the inflow of clean ocean water brings increased oxygen. An example of this phenomenon is shown in Figure 2. In the Hudson River above 42nd Street, the end of the flood brings low oxygen and the end of the ebb brings down quantities of well-oxygenated water from upstate. The same conditions prevail in the Upper East River, the flood current carrying pollution and low oxygen, and the ebb carrying clean water from Long Island Sound. In the Harlem, the effect of the tide is to throw the point of minimal oxygen up or down the river from Willis Avenue near the East River to Morris Heights at Dyckman Street. At the end of flood current, the lowest oxygen is found at Willis Avenue, and at the opposite end of the tidal cycle it is found near Morris Heights.

Seasonal Variations

Then there is the seasonal variation. In midwinter the entire harbor outside the pierhead lines, with the exception of a number of small creeks,

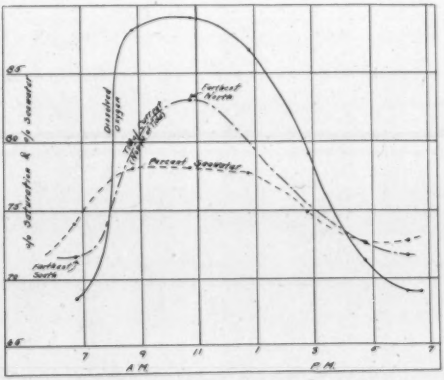

FIG. 2.—Tidal Variation in Dissolved Oxygen, The Narrows, Sept. 26, 1911.

is plentifully supplied with oxygen. With the coming of early summer the oxygen begins to drop and reaches its minimum generally about September 1st. This change appears to be due to two causes—increased temperature, which brings about greater bacterial activity with conse-

quent drain on the oxygen present, and decreased flow of upland water resulting in diminished oxygen supply. Figure 3 shows the annual cycle. The rising oxygen in March and April is best explained as due to spring freshets.

Annual Variations

We now come to the third and vital variations from year to year over a long period. Inspection of Figures 4 and 5 shows two outstanding phenomena, namely, a noticeable net fall in oxygen from 1909 to date, and a marked irregularity in that fall. Furthermore, the downward pitch of the curve is more steep in the period from 1909 to 1921 than in the period from 1921 to date. This easing off in the rate of oxygen depletion can be most satisfactorily explained on the basis of the well-established law of oxygen absorption by water from the atmosphere. The rate of absorption increases the further the dissolved oxygen falls below the saturation point, there being no absorption when the water is saturated and

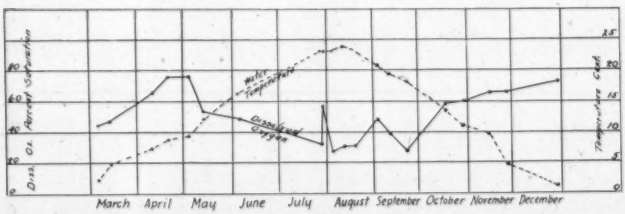

FIG. 3.—Seasonal Variation in Dissolved Oxygen, Pier 10, East River, 1917.

there being a maximum when the water is devoid of oxygen. By 1921 the oxygen had fallen to somewhat less than half the 1909 values, and in 1926 the figures were still lower. The intervening years and those subsequent to 1926 show higher values.

The irregularities evident to even a casual observer of the diagrams merit considerable discussion. That they are not due to fluctuations in pollution seems self-evident. The volume of polluting material is known to be increasing at a steady rate. Why, then, should the oxygen be sometimes greater and sometimes less, with a general trend to lower values? Since 1919 efforts have been made to solve the riddle. As a result of rather extensive studies the two principal factors influencing the amount of oxygen, aside from the polluting material, are volume of clean upland water and air temperature. There are, undoubtedly, other influences but such of these as are a matter of record form no consistent part of the picture.

Attention is called to Figure 5, on which are displayed the sum of the flows of the Hudson River at Mechanicville and the Mohawk River at

Cohoes taken from the U. S. Geological Survey records, the ordinates representing cubic feet per second, the air temperature at New York, from the Weather Bureau records, and the grand average dissolved oxygen for the main harbor of New York. The fluctuations occurring in the

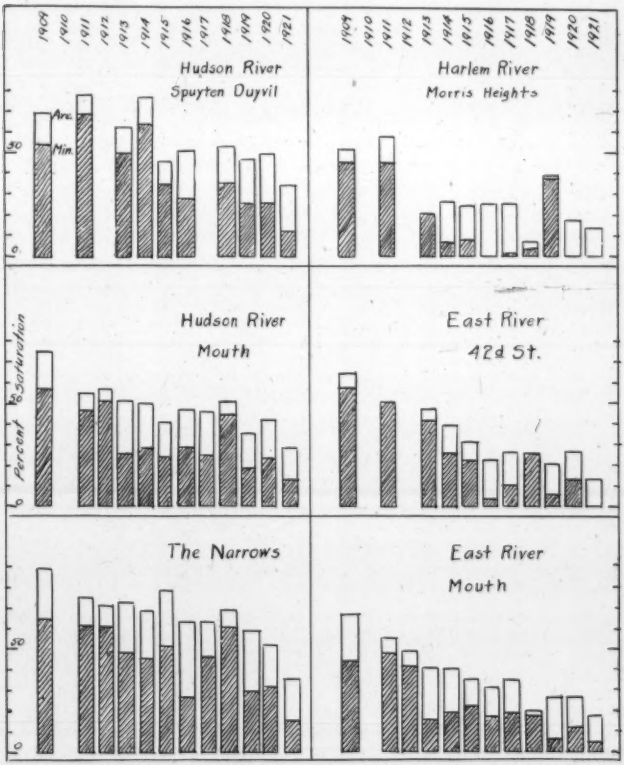

FIG. 4.—Annual Variation in Dissolved Oxygen, 1909 to 1921.

various divisions of the harbor almost without exception parallel those of the grand average, and they are omitted for the sake of having a clearer diagram.

It will be observed that the years 1921 and 1926 show exceptionally low oxygen averages. In 1921 complete depletion of oxygen was observed in the middle of the East River for the first time on record. In 1926, the same phenomenon, zero oxygen, was noted three times. As will be seen from the chart, the first of these slumps was accompanied by a combination of circumstances both favoring such a condition—very low flows of upland water, and unusually high temperatures in the territory around New York. In the following year, 1922, there was an enormous increase in upland water and a fall in mean temperature, resulting in a rising oxygen content. In 1925 there came another summer of high up-

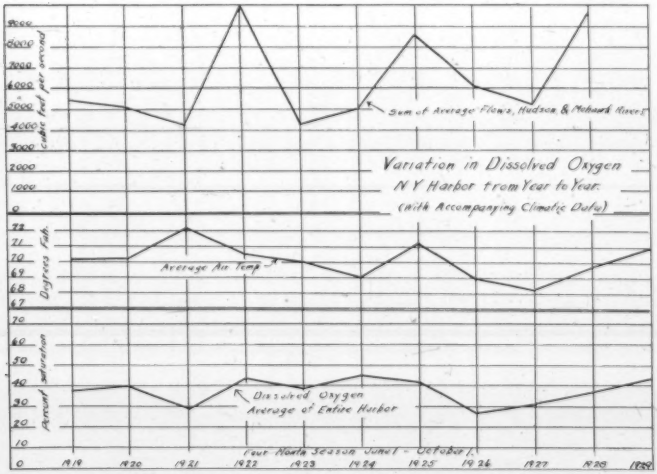

FIG. 5.—Annual Variation in Dissolved Oxygen, 1919 to 1929.

land flow but accompanied by high temperatures so that the oxygen fell off from the 1924 value to a slight degree. The 1926 oxygen deficiency was the most severe on record, but the upland water was not by any means at its lowest and the temperature was somewhat below normal.

There has been a steady climb in oxygen since 1926. The increase in 1927 can be reasonably accounted for by the lower temperatures in spite of low stream flow, and the further increase in 1928 by the very high stream flow. The still further increase in 1929 requires a good deal of explaining, and after every possible explanation has been considered,

the figures remain somewhat anomalous. Unfortunately, the stream flow data are not yet available, but the gauge heights of the Hudson at Albany for June to September indicate discharges less than normal. New York temperatures were somewhat above normal so that we should expect low oxygen. If we examine the season's work in detail, we shall note one or two things in the conduct of the work itself tending toward a high average figure. The boat was in the repair shop throughout July so that June, always the highest in dissolved oxygen results, furnished a disproportionate number of samples. Had the usual number of July samples been included, the average would probably have been lower. Furthermore, although the Hudson was low in June and later, in May it was well above normal. The effect of high water in May might well continue into June at a point 150 miles farther down the stream.

Wind velocity has been shown to be an important factor in shallow bodies of water, but it is impossible to trace its effect on New York Harbor in general averages. In 1929 it was practically normal, so that the high figures cannot justly be laid to that source. The percentage of sunshine in 1929 was the highest since 1919. The oxygen results for 1929 showed the highest percentage of samples above 100 per cent saturated. An oxygen content greater than 100 per cent can arise from only one source in nature, namely, marine chlorophyl-bearing plants, and as these can function only in sunlight it would seem as though there should be a relation between the amount of sunshine and the growth of green plants, with a corresponding rise or fall in oxygen. A complete study of the records shows no definite relation except in 1929, hence the conclusion that the high figures of that year were due to this cause can only be tentative, and subject to further confirmation or disproof.

Variations in Harbor

Only certain portions of New York Harbor are low in oxygen. The Hudson is at all times well above the danger line. The Upper and Lower Bays are, in general, good, despite the discharge of large volumes of sewage from the Passaic Valley outlet. Kill van Kull and Arthur Kill are also well aerated except near the outlet of the New Jersey joint sewer at Bayway. Here the oxygen values at times approach zero, with the attendant danger of local nuisance. The Upper East River, east of a line from Baretto Point to Rikers Island dock, is always well over any conceivable danger point. Jamaica Bay shows low values in the vicinity of the outfall of the twenty-sixth ward screening plant, accompanied by distinct sewage odor. The rest of the bay is always near saturation and frequently shows supersaturation. This latter is often accompanied by a green turbidity suggesting myriads of chlorophyl-bearing microörganisms. The Harlem River for a large part of its course is almost an open sewer, with

summer values always under 10 per cent of saturation and with zero values occurring a number of times each summer. The Lower East River is the most highly polluted of the larger bodies of water comprising the harbor. At times its waters show oxygen as low as that of the Harlem River samples, although these low amounts are of a more transient character; a fresh inflow of Upper Bay water on the flood tide always brings the oxygen over the danger point. This depleted condition extends into the Upper East River past the location of the outfall of the projected Ward's Island activated sludge plant. It is confidently to be expected that the initiation of service in this plant will forever remove from the Harlem and Lower East Rivers any danger of nuisance.

Summary

We have seen that, in general, there has been a marked decrease in the oxygen content of the harbor since 1909, and, further, that the rate of fall since 1921 has been apparently less rapid than before. We have noted three types of variation, a tidal variation, a seasonal variation and a variation from year to year. The figures since 1919 have shown considerable annual variation, the principal causes of which appear to be fluctuations in the flow of upland water and in air temperature. The 1929 figures show the marked influence of some other factor, and it is suggested tentatively that this might be abnormal growth of green water plants stimulated by an abnormally large percentage of sunshine. The Harlem and Lower East River are in a condition which might give rise to nuisance under suitable conditions, but which will be made entirely safe by the construction of a treatment plant on Ward's Island.

New York's Sewage Problem.—Dr. George A. Soper has reviewed plans for the disposal of New York's sewage, starting with the formation of the New York Bay Pollution Commission in 1903 and the Metropolitan Sewerage Commission in 1906, of which Dr. Soper was President. The recommendations of this commission up to 1914 comprised mainly grit chambers and screens, with the construction of an island off Sandy Hook to which 200 m. g. d. would be taken for sedimentation and dispersion. This project is compared favorably with the present plan by which 180 m. g. d. will be treated by activated sludge at Ward's Island. The lower East River may require further relief. Dissolved oxygen is lowest in the Harlem River, Lower East River and Upper Bay. Local shore nuisances are present throughout the entire metropolitan district.—*Municipal Sanitation*, **1**, 147–151, 205–211, March and April, 1930.

Editorial

Sludge Digestion

The digestion of sewage sludge has undoubtedly been the subject of greatest interest in the field of sewage treatment during the past several years. Certain research laboratories and organizations have been specifically identified with this development. It is gratifying to be able to present, in this issue, original papers from most of these organizations. The names of the authors are well known: Buswell of Illinois; Keefer of Baltimore; O'Shaughnessy of Birmingham; Rudolfs and Heukelekian of New Jersey; and Sierp of Essen. Mr. O'Shaughnessy chose to discuss activated sludge, although he is equally as well or better known for his work on separate sludge digestion.

Dr. Sierp offers some very stimulating ideas concerning the heat properties of digesting sludge. It may be quite a surprise to most of us to know that enough heat is generated spontaneously by digesting sludge to cause the marked differences in the curves of heating and cooling shown in the paper by Dr. Sierp. The practical significance of this phenomenon is difficult to estimate; likewise the other conclusions with regard to heat conduction, convection and insulation only show the way toward similar tests on larger scale—10,000 times as great in volume, as suggested by Dr. Sierp—but he has undoubtedly furnished material for careful consideration in the problems of heating sludge. In this country hot water is not introduced directly, but Dr. Imhoff's convictions as to its desirability certainly carry weight. Dr. Sierp offers experimental data to substantiate these convictions. Very near their "home town" of Essen, however, Dr. Prüss heats sludge in auxiliary tanks by pipe coils, through which hot water is circulated. The accumulation of further data such as presented by Dr. Sierp, when supplemented by actual plant operating data, will go far toward demonstrating the relative ease, economy and efficiency of such alternative procedures.

Dr. Buswell for some time has been advocating the circulation of sludge liquor, with spray distribution over the surface of the scum. He claims this will soften and sink the scum, hasten digestion and increase the rate of gas production. His paper in this issue describes this procedure in connection with studies of two-stage digestion. It may be possible to combine the procedures recommended by Drs. Sierp and Buswell; the former would heat sludge liquor and introduce it at the bottom of the tank, the latter

would introduce it over the scum. Is it desirable to split the flow and would such procedure combine the desirable features of both suggestions?

The work of Drs. Rudolfs and Heukelekian on thermophilic digestion is attracting widespread interest. Dr. Heukelekian gives further data of interest in this, his second paper on this subject. Many interesting possibilities are suggested as advantages of high-temperature digestion. The short time required and low moisture content of the digested sludge are powerful factors in favor of this procedure; on the other hand, the high temperatures required introduce problems of heating and insulation far in excess of those now being studied in heated separate digestion tanks. As Dr. Heukelekian states, it is a far cry from accomplishing such results in the laboratory, where the material is put into an electrically controlled incubator, to duplication of results in actual plant operation. The restraint and conservative attitude demonstrated by this statement are to be commended.

Baltimore has been the American Birmingham in considerations of separate digestion, but has occasionally been cited as an example of the difficulties of separate digestion. The reasons for the major difficulties that have been encountered at Baltimore were demonstrated during the course of the tests reported by Keefer and Rudolfs. Only consider their statement that "unseeded sludge, the pH of which was not controlled, was only partially digested after a period of 850 days." The high acidity developed by this sludge, the large cold tanks, and difficulties in thorough mixing of ripe and fresh sludge account for the large storage space required and occasional difficulties from undigested sludge. The results of operation of the Baltimore tanks should not be considered as representative of the procedures now in development in separate sludge digestion. Keefer and Rudolfs show that the use of lime would greatly accelerate the rate of digestion of Baltimore sludge, and it is to be assumed that heat would still further improve results.

Notwithstanding the remarkable progress in research on separate sludge digestion it must be admitted that complete records of operation of large plants over a period of years are almost totally lacking, at least under the conditions of loading or shortened time of digestion indicated by small-scale tests. There is not much value in the study of results of operation of plants that are operating far below their designed capacity, or in which the presence of industrial wastes makes it impossible to apply the results to any other conditions.

Within a few years these badly needed plant records may be available. For the present, our Federation is indebted to the authors of the papers in this issue for their combined efforts to throw more light on this complex problem of the digestion of sewage sludge.

Research—and the Open Mind

The development of practical processes of sewage treatment is dependent primarily on the utilization of the results of research or investigations on a small scale. Laboratory research, experimental plants and testing stations are commonly used to discover and perfect new methods or processes of sewage treatment. Few truths are discovered accidentally or promiscuously by the experimental method. The usual procedure is something like this: The experimenter or director of the work has made certain observations, calculations or experiments which indicate to him that he might be able to modify or augment known processes by changing the conditions of operation. Experiments are then planned in such a way that these observations or hypotheses may be proven or disproven. Demonstration of the proof or disproof rests upon the interpretation of the data accumulated during the course of the work. The conditions of experiment always require study of a number of factors of unequal importance. The best conditions of experiment are those in which only a few of the factors are variable but in which the fundamental factors, such as the composition of the material, its mass and volume, or the efficiency desired, are constant. Such conditions are fulfilled far more satisfactorily in working with engineering materials or physical entities than in working with biological or living organisms. For this reason the results obtained in physical or chemical research are more definite and more easily interpreted than those obtained in biological or biochemical research, and less judgment of the experimenter is required in order to interpret the results and draw the conclusions.

Research in treatment of sewage is concerned primarily with living organisms and a heterogeneous mass that varies from day to day and even hour to hour. Consider the variables in, let us say, studies of sludge digestion or the activated sludge process. Only a few of these are: composition of sewage, temperature, reaction and moisture content of sludge, amount of air, concentration of sludge, aeration period, depth of tanks and time of settling. The conclusions must be drawn from a consideration of analytical results obtained during a series of experiments in which most of these factors are maintained constant, as nearly as possible, while others are varied. It is never possible to feel entirely satisfied that conditions in comparative tests were truly comparable. It is usually impossible to maintain controls over long periods, consequently it may be necessary to compare results throughout a few weeks or months with other results obtained earlier or later. One can never be certain that the sewage used did not vary, temperatures certainly are different at different seasons, and the vagaries of storms, with the resultant effect of storm-water sewage, may be classed as acts of God.

The experimenter must consider all of these variables, plan his work so that they will have the least possible effect on results, and then draw his conclusions after taking into account the degree to which the actual conditions diverged from those contemplated when the tests were planned. This requires unbiased judgment. In many cases it is found that the conditions were so far from those contemplated that no conclusions can be drawn. Frequently, also, necessary studies are overlooked during the course of the experiments, and their essential value realized only after the work is concluded. It is then that the experimenter must be frank with himself and not stretch his credulity or that of his readers sufficiently to state that certain hypotheses were proven or disproven. In fact, a fairly critical experienced observer, free from personal bias, usually finds that in most experimental studies of sewage treatment clear-cut conclusions are not warranted but must be made with reservations.

This is where the title of this editorial comes in—the open mind. All of us like to feel that we have proven our thesis by indisputable data. But we should be frank with ourselves and hypercritical of our results, unless the proof of the hypothesis is positive. Those who report the results of sewage research should have an open and unbiased mind, quick to detect flaws in brilliant gems of thought, and ready to point out qualifying or nullifying factors indicated by the operating and analytical results.

Rejuvenated Sludge

It seems as though we have suddenly realized that that black sheep of sewage treatment—sludge—has not been treated very well in our past conceptions of a satisfactory scheme of sewage treatment. We have allowed the sludge to be numbed by cold in winter; we have created aggravated cases of indigestion by failure to provide a balanced diet for the hungry organisms, which, not knowing any better, have eaten too much fat and cellulose for their own good, thereafter stewing for months (yes, years at Baltimore) in their own acid pH juices; we have precipitated the solids into oblivion and, if possible, have forgotten about them from fall until summer, unless they appear suddenly in gas vents early in the spring, crying for recognition (and lime). No, we haven't been very solicitous about the environment or fate of sewage solids, but now we are going to make up for these many years of neglect and mistreatment. We will coddle the outcast in heated, well-insulated tanks; we will plan a well-balanced diet for it, including a little soda or lime if there are occasional indications of indigestion; and no longer will we let it lie quietly in the bottom of a tank—oh, no, we will pep it up by pumping and stirring it

from top to bottom or from bottom to top, from the walls to the center, or from the center to the walls.

With all this attention and concern for optimum conditions, surely all the former woes of sludge disposal will be eliminated. Appreciation of these attentions will be shown by a rejuvenated sludge, eager to digest and ascend the pH scale to 7.4, that goal of all sewage solids that must be reached before the Nirvana of the sludge-dump can be attained. No longer will the solids associate with the riffraff and scum which formerly crowded into the gas vents and spilled over the surface of the sewage, but they will be travelling so often and so fast from one part of the tank to another that they can't loiter and collect in any one place to hatch up troubles for the plant operator.

But an even more marvelous metamorphosis is in prospect. The effluvia and noisome emanations which formerly gave sludge its bad name are to be transformed into odorless gases, rich in B. t. u., which will warm the sludge, run engines, furnish the power for the sewage treatment works, light and heat our homes and otherwise reward us. It now seems that sludge was not such a bad actor, but that its bad name was due to improper housing conditions, lack of heat, and association with fresh, unstable organisms lacking in the proper equilibrium. These conditions are bound to result in a sour or acid disposition and the exhalation of a sulphurous aura.

After we have educated sludge and prepared it for association with polite society, we may hope that it won't mock our efforts by developing halitosis, so that we will have to turn our heads and noses the other way. But if such base ingratitude should greet us, a good shot of chlorine may be able to cure that bad breath and likewise improve digestion.

We must be careful, however, not to wear out the sludge by too much stirring, circulation or *umwälzung*. The merry dance of the may-fly ends only too soon in death and decay; too active sludge may suddenly crack under the strain of this modern, hurrying life and sink down into an inert, lifeless mass, fit only to be buried.

Let us add a new term to our glossary of sewage treatment: rejuvenated sludge. Steinach and Voronoff have their confrères among the sanitarians, who have rescued that ancient pariah, sludge, from its former degradation, and by proper inoculation and thermo-therapeutics, have given it a new lease on life and a hopeful outlook for the future.

Proceedings of Local Associations

Texas Water Works Short School, Twelfth Annual Meeting

Abilene, Texas

January 27–30, 1930

The Twelfth Annual Meeting of the Texas Water Works Short School was held from January 27 to 30, 1930, at Abilene, Texas, with a total of 272 registrants. The meeting was divided into two sections—laboratory and general.

Mr. Jack J. Hinman, Jr., President of the American Water Works Association, extended greetings from that organization. "The Developments in the Treatment of Highly Polluted Water in the Removal of Bad Tastes and Odors" and "Conclusions at the Chicago Filtration Plant" were presented by Mr. John R. Baylis of Chicago. Other subjects presented for discussion were those on cross connection control and the new departure of the sewage treatment layout at Cleburne, Texas. At a round-table conference on the 27th, filling stations and the manufacture of chlorine in Texas were discussed. The importance of daily tests for residual chlorine and the inclusion of ortho-tolidine testing apparatus in plant equipment was stressed, and the State Department of Health Engineering Division was requested to prepare a sketch for such an outfit. During the business session standing committee reports were presented as follows:

W. S. Mahlie, Chairman of the Sewage Division, outlined the work of the Federation of Sewage Works and urged all those present to subscribe to the SEWAGE WORKS JOURNAL.

L. A. Quigley, Chairman of the Membership Committee, reported that the 1929 records showed that there were 65 active and 26 associate memberships in Texas.

Progress reports by G. L. Fugate, Chairman of the Stream Pollution Committee, and Arthur M. Crane, Chairman of the Committee on Certification and Classification, will be included in the printed Proceedings. Waco, Texas, was selected as the next meeting place of the School. The nominating committee submitted the following names for officers for 1930 which were unanimously elected by the convention.

President: L. A. Grimes, Abilene; *First Vice-President:* W. H. Deaton, Waco; *Second Vice-President:* Bud A. Randolph, Houston; *Third Vice-*

President: J. R. John, Dallas; *Fourth Vice-President:* George Mincy, Tyler; *Secretary:* V. M. Ehlers, Austin; *Treasurer:* E. G. Eggert, Austin.

Florida Short Course in Water and Sewage Treatment

Gainesville, Florida

April 10–11, 1930

The General Extension Division of the University of Florida offered this year for the first time a Short Course in Water and Sewage Treatment in coöperation with the State Board of Health and the Florida Section of the American Water Works Association. The annual meeting of the Florida Section was held at this time that it might merge with the Short Course. The course was planned in the interest of those actively engaged in water and sewage treatment.

On Tuesday afternoon three general lectures outlining the field to be covered were presented. In the evening under the subject of coagulation were discussed coagulants, chemistry of colloids, chemical reactions in floc formation, technique of jar tests and the theory and determination of the pH value of water in relation to floc formation.

The topics Wednesday morning dealt with water bacteriology and standard methods. These were followed by a discussion of chlorination, its chemical action on organic matter, production of tastes and odors and their removal, dosages employed, tests for free chlorine and efficiency in removal of bacteria. In the evening, sewage treatment was discussed with particular reference to Imhoff tank operation, mechanical equipment in sewage treatment and protection of water supplies from contamination.

The program consisted of fifteen lectures of 40 minutes each, followed by a 20-minute discussion period.

Oklahoma Water and Sewage Conference, Notice of Sixth Annual Meeting

The Sixth Annual Meeting of the Oklahoma Association will be held in conjunction with the Oklahoma Water Works Short School from May 11 to 15, 1930, in the Engineering Building of the Oklahoma A. and M. College, Stillwater, Oklahoma.

The Association will meet at the Ardmore City Hall May 11 and 12 for an inspection trip, which will include Ardmore, Durant, Muskogee, Tulsa and other cities enroute.

The papers dealing with sewage disposal and research will discuss hydrogen-ion control, Imhoff tank design, working principles of sewage tanks, filters, sludge and sludge disposal, eliminating odors, discussion of the Lawton plant and the activities of the state sanitary engineer's office.

Central States Sewage Works Association, Notice of Third Annual Meeting

The Third Annual Meeting of the Central States Association will be held June 9 and 10, 1930, at Springfield, Illinois.

Arrangements are being made to include an inspection trip of the Decatur and Urbana plants and possibly Bloomington.

Notice of Second Annual Convention, Virginia Water and Sewage Works Association

Norfolk, Virginia

June 19–20, 1930

The Second Annual Convention of the Virginia Water and Sewage Works Association will be held at the new Nansemond Hotel, Ocean View, Norfolk, Virginia, June 19th and 20th. The program will include a number of interesting papers dealing with plant operation and treatment of raw water supplies. Papers and discussions concerning impounding reservoirs and maintenance of watershed areas, and the application of advantageous methods of sewage treatment will also be presented.

Pennsylvania Sewage Works Association, Notice of Fourth Annual Conference

The Fourth Annual Conference of the Pennsylvania Association will be held June 26 and 27, 1930, at State College.

Reviews and Abstracts

H. W. STREETER

The Effect of Activated Sludge on Pathogenic Organisms

ABSTRACTED BY G. P. EDWARDS

Although a number of investigations have been made to determine the effect of the activated sludge process on the bacteria present in sewage, very little study has been given to the effect on pathogenic organisms.

In 1922 Courmont and Rochaix[1] aerated sewage mixed with $12^1/_2$ per cent activated sludge until purification was complete as indicated by the disappearance of ammonia. At the end of this five-or six-hour period, they obtained reductions in bacteria varying from 0 to 56 per cent when samples were plated on gelatin. Prolonged aeration up to two weeks caused nearly complete disappearance of bacteria. The few remaining organisms were aerobic. When a mixture of sewage and sludge, inoculated with typhoid and paratyphoid bacteria, was aerated for the normal period of five or six hours, the pathogenic organisms were nearly always found in the effluent. Inoculated sewage aerated in the same way without activated sludge gave similar results. Under the same conditions, cholera vibrio disappeared. Organisms of the typhoid and paratyphoid group disappeared after two or three days whether aerated or not. These bacteria as well as cholera vibrio persisted a long time when aerated in a sterile sewage or a sterile mixture of sewage and sludge. They concluded that the growth of these organisms was not affected either by activated sludge or aeration but that the reductions seemed to be due to bacterial antagonism.

In 1927, H. Bruns and F. Sierp[2] also investigated the effect of activated sludge on pathogenic organisms. In preliminary experiments using activated sludge, they obtained in a five-hour aeration period 95 to 98 per cent reduction in total counts with a large reduction in *B. coli*. Typhoid organisms nearly disappeared in a short time from the effluent of the aeration tanks, but they were found even after a week in the sludge.

A culture of typhoid bacteria was added to eight liters of sewage containing 15 per cent activated sludge and the mixture was aerated in a small

[1] P. Courmont and H. Rochaix, *Revue d'Hygiene*, **44**, 907 (1922).

[2] H. Bruns and F. Sierp, *Zeit. f. Hyg.*, **107**, 571 (1927).

experimental activated sludge plant. These eight liters of sewage and sludge contained 3.6 billion typhoid bacteria. The effluent was discharged at the rate of 1800 cc. per hour, giving approximately a six-hour period. An 80 cc. sample of the effluent was collected each hour for tests. The samples were plated on Endo and Drigalski agar which was incubated 24 to 48 hours. The results as shown in Table I indicate that only 153 million, or 4.2 per cent, of the organisms were recovered.

In the same manner, other tests were made varying the organisms, the aeration period and the amounts of sludge. When sewage inoculated with typhoid bacteria was aerated for three hours in contact with 15 per cent sludge, a reduction of 96 per cent was obtained. Two tests with paratyphoid organisms gave decreases of 97 and 98 per cent, respectively. Among the other organisms, Shiga-Kruse bacteria showed reductions of 97.5 per cent, Flexner and Y bacteria 97 to 98 per cent and cholera vibrio nearly 98 per cent. Varying the amount of activated sludge from 5 to 20 per cent caused very little difference in results. It seemed, however, that slightly better reductions were obtained with 15 to 20 per cent sludge than with 5 to 10 per cent.

To determine the effect of activated sludge and aeration on spores, an anthrax culture rich in spores was heated to 80° C. for five minutes in order to kill vegetative forms. These spores were added to sewage containing 12 per cent sludge. After six hours of aeration, about 50 per cent of the spores were recovered in the effluent.

Bruns and Sierp concluded that the clear effluent from the activated sludge process became practically free from pathogenic organisms in a relatively short time. The sludge, however, retained the organisms for a much longer time. Organisms forming spores were much more resistant than the sporeless type, as only about 50 per cent of them were removed in the process.

Since Bruns and Sierp obtained a rather rapid decrease in pathogenic organisms during aeration with activated sludge, as compared with the slow reduction reported by Courmont and Rochaix, Pesch and Sauerborn[3] decided to experiment with paratyphoid B (Schottmüller) bacteria in Cologne sewage. They selected this group of organisms because they are easily recognized by their typical colonies when grown on Endo agar and malachite green agar, which is incubated at 37° and then 22° Centigrade.

Cologne sewage mixed with 10 per cent activated sludge was inoculated with paratyphoid B bacteria and aerated. Samples were collected every hour for eight hours and at longer intervals thereafter. Dilutions of 1:100 to 1:10,000 were plated on Endo and malachite green agar. The results are shown in Table II. No paratyphoid bacteria were found either

[3] K. L. Pesch and E. Sauerborn, *Gesundh. Ing.*, **52**, 856 (1929).

in the original sewage or sludge when diluted as above. As may be seen, a reduction of about 50 per cent was obtained during the first hour. Pesch and Sauerborn do not believe this reduction to be due to aeration nor to bacterial antagonism, since the time was too short. It is possible that some of the bacteria were eaten by infusoria and it is quite probable that many of them were adsorbed on the activated sludge floc. This is merely a pseudo decrease and not caused by death of the organisms. After the first hour, the number of organisms was reduced gradually until in 24 hours there was about 95 per cent reduction. In this same length of time Bruns and Sierp obtained a 99 per cent decrease. In one experiment made by Pesch and Sauerborn, although the paratyphoid organisms decreased in the sewage from 4,600,000 to 5700 per cc., there were 1,020,000 per cc. in the sludge. Bacteriophage may play a part in this reduction of organisms, although in some experiments bacteriophage for typhoid or paratyphoid was not found in the activated sludge after aeration.

Table III summarizes some of the results reported in the three papers. Although the results obtained by Courmont and Rochaix on pathogenic organisms are qualitative, they seem low as compared with those of Bruns and Sierp. The reductions obtained by Pesch and Sauerborn were intermediate.

TABLE I

RECOVERY OF TYPHOID BACTERIA IN THE EFFLUENT OF ACTIVATED SLUDGE TANK

Experiment started 11:00 A.M., April 13, 1926. Temperature of sewage, 11° C. Eight liters of sewage contained 3600 million bacteria.

Time	Typhoid Bacteria in 80 Cc. of Sewage Thousands of Bacteria	Typhoid Bacteria in 1800 Cc. of Sewage Millions of Bacteria
11:00–12:00 Noon	689	15.5
12:00– 1:00 P.M.	1015	22.8
1:00– 2:00 P.M.	1306	29.4
2:00– 3:00 P.M.	1178	26.5
3:00– 4:00 P.M.	1152	25.9
4:00– 5:00 P.M.	693	15.5
5:00– 6:00 P.M.	397	8.0
6:00– 7:00 P.M.	258	5.8
7:00– 8:00 P.M.	102	2.3
8:00– 9:00 P.M.	33	0.74
9:00–10:00 P.M.	35	0.78
10:00–11:00 P.M.	6	0.01
11:00–12:00 Midnight	10	0.02
12:30– 1:00 A.M.	4	0.009
1:00– 2:00 A.M.	1	...
	Total	153.259 Million

TABLE II

DECREASE IN PARATYPHOID COLONIES DURING AERATION

Time	Paratyphoid Colonies	Time	Paratyphoid Colonies
June 5—10 A.M. (initial)	800,000	June 5— 4 P.M.	210,000
11 A.M.	300,000	5 P.M.	180,000
12 Noon	380,000	6 P.M.	270,000
1 P.M.	400,000	10 P.M.	144,000
2 P.M.	250,000	June 6— 8 A.M.	70,000
3 P.M.	290,000	10 A.M.	35,000

TABLE III

REDUCTION OF BACTERIA IN THE ACTIVATED SLUDGE PROCESS

Summary of Results

Author	Total Counts 5–6 Hours	Typhoid Groups 5–6 Hours	Typhoid Groups 24 Hours	Cholera Vibrio 5–6 Hours
Courmont and Rochaix	0–56%	Organisms present	Organisms present	Organisms negative
Bruns and Sierp	95–98%	96%	99%	98%
Pesch and Sauerborn		74%	95%	

Aerating Sewage

BY JOHN L. MASON

Western Construction News, **4**, 523–25 (October 10, 1929)

ABSTRACTED BY J. K. HOSKINS

This article describes the "Watsco" aerator, a mechanical device for aerating sewage in the activated sludge process of treatment.

The theory, history and development of the activated sludge process are reviewed at some length and the essential requirements of aeration tanks for successful operation are stated. The "Watsco" aerator, which is designed to meet these conditions, "consists of a direct-connected, semi-displacement, screw-type pump discharging downward through a restricted section or venturi throat. Air is drawn into the sewage stream at the throat by the suction which the flow through the restricted section produces." Complete emulsion of air in the sewage is produced and mixture with the tank contents is assisted by the introduction of a conical baffle near the bottom which imparts a spiral flow effect. The amount of air introduced can be varied by changing the ratio of the area of the restricted section to that of the straight section.

Initial results obtained from tests of a unit installed at Montezuma School, California, indicated a reduction of B. O. D. in the aerator of 90.5 per cent, a clear effluent and a light brown sludge. Observations of operating results indicate that at least 20 per cent of the oxygen supplied to the sewage is available for oxidation of the organic matter.

"Applied to a standard 'Watsco' unit, which is capable of emulsifying 1600 gal. of sewage and 320 gal. of free air per minute, the capacity of an aerator is calculated as follows:

Rate of circulating sewage liquor	1600 g. p. m.
Quantity of air entrained in liquor, 320 g. p. m. or	42 cu. ft. per min.
Pounds of oxygen furnished at 80° F. 760 mm. pressure	0.7 per min.
Pounds of oxygen in 6 hours	250
Quantity of 100 p. p. m. B. O. D. sewage which aerator will treat in 6 hours	60,000 gal.
Daily capacity of standard aerator unit, 100 p. p. m. B. O. D. sewage, 6 hours' retention	240,000 gal.
Horsepower requirement	2.68 h. p. per unit

To determine the capacity of the unit for any given sewage, multiply 240,000 gal. by

$$\frac{100}{\text{B. O. D. in p. p. m. of sewage under consideration}}$$

"

Review of Sewage Treatment Progress in England in 1929

The Surveyor, **77**, 113–18 (Jan. 31, 1930)

ABSTRACTED BY H. W. STREETER

In spite of the progress made in the treatment of sewage and industrial wastes during the past 30 years, the pollution of streams in Great Britain appears to be becoming worse. This condition, resulting from the rapid increase in sewered population and the creation of new industries, is the more important because of the growing need to obtain water supplies from rivers.

During the past year, British visitors to Germany have observed the marked advances made in the efficiency of sludge digestion and gas production, notably in the new system devised by Dr. Prüss. Digestion tanks of the Prüss type have yielded an increased digestion capacity of 50 per cent and a total volume of gas twice as great as obtained from the old tanks. Sludge is warmed in these tanks by adding cooling water from the gas engines, or by heat generated from the gas collected. An important

feature is a mixer in the settling tank, similar in principle to the "Simplex" aerator. In practice, the mixer is operated and sludge drawn off daily, thereby decreasing the required capacity of the sedimentation tank. Considerable advantage has been found in mixing new and old sludge, as the fermentation is more rapid and more gas is produced. A period of 30 days has been found sufficient for digestion to an innocuous and readily dewatered residue. Digested sludge usually has a moisture content of 80–85 per cent and air-dried sludge, about 60 per cent. The volume of dried sludge is about $^1/_{10}$ that of the raw sludge added to the digestion tanks.

Among the new works constructed in Great Britain have been those at Staveley, Airdrie and Stafford, together with important extensions of the existing plants at Epsom and Bradford. In connection with the Stafford plant, it is interesting to note the success of the activated sludge process in treating sewage containing gas liquor, which constitutes about $^1/_6$ of the total volume of flow.

At Bradford the construction of 6 acres of percolating filters has brought the total filter area up to 38 acres. These filters have been filled with coal, sizes $^1/_2$" to 1", to a depth of 6 feet. In order to deal with the sewage and trade waste (the latter consisting mainly of wool-scouring waste), 20,000 tons of sulphuric acid are used annually as a precipitant. The acid is manufactured at the plant. The sludge is passed by gravitation to presses for the recovery of by-products. The importance of these by-products at Bradford may be judged by the fact that the total sum recovered from the sale of grease and manure during the 27 years extending from April 1, 1902, to March 31, 1929, amounted to $6,000,000, or an average of $222,000 annually.

Considerable interest is being manifested in the two-stage treatment of sewage at Birmingham and Croyden, the additional stage consisting of bio-aeration of the effluent of the settling tanks before it reaches the percolating filters. The possibility of using a three-stage process, as suggested by Mr. F. C. Temple, has been exemplified by its adoption for the treatment of yeast waste in Finland.

A further development of interest, described by Mr. D. E. L. Davies, is the use of a new brushwood filter at Cape Town, South Africa, where this material is abundant. Although brushwood has a shorter life than broken stone, it is stated as being capable of treating at least three times the volume of tank effluent. The success of this filter is attributed by Mr. Davies as being in part due to the South African climate.

An important event of the past year has been the publication of a report on standard methods of analysis issued by the Ministry of Health. A further report, dealing with methods of cost accounting at sewage works, has been promised.

In a paper given before the Royal Sanitary Institute, Mr. J. H. Garner stated that in England the problem of river pollution is the result of industrialization, but that inactivity and lack of public interest are causes of the present condition. A comprehensive plan for conservation of the water resources of the country and the use of streams in a way which will benefit the greatest number of people for the longest time is urged by Mr. Garner. It is generally agreed, he states, that the country should be divided into catchment areas, as recommended by the Royal Commission on Land Drainage in 1927, and that all streams in each basin or group of basins should be under one authority.

The pollution of streams by ochre pumped from mines presents a difficulty which cannot be overcome without amendment of the existing law, and a new difficulty has arisen from pollution by storm-water due to the rapid run-off of rain from the impervious surfaces of modern roads. Some revision of the Ministry of Health requirements respecting the settling of storm-water overflow and treatment of storm-water is desirable.

In a paper read before the Association of Managers of Sewage Disposal Works, Mr. H. D. Bell described studies of chlorination made at the Stratford-on-Avon and Barnsley sewage works, noting also the results of previous work in America and at the Bath (Eng.) plant. From Mr. Bell's study he found that less chlorine is required to prevent septic action than to remove the hydrogen sulphide resulting from such action; hence the prevention of septic action effects considerable economy in deodorization. He observed that bleaching powder, by restricting septic action, renders the work of purification more adequate in dealing with stronger sewage, thus aiding oxidation devices, such as filters and the activated sludge process. He further noted that bleaching powder also is an active precipitant, is capable of revivifying humus returned to a bio-aeration unit, reduces flies on filters and does not interfere with purification processes; it also facilitates sludge treatment.

Sludge Treatment in Sewage Disposal

BY T. P. FRANCIS

The Surveyor, **77**, 243 (February 14, 1930); 281 (February 21, 1930)

ABSTRACTED BY C. T. CARNAHAN

The usual British practice of sludge disposal consists of disposal on land, lagooning, pressing or barging to sea. All of these methods are expensive and are not satisfactory, as they create more or less nuisance. In Germany, on the other hand, sludge is disposed of with little or no nuisance

at a reasonable cost by digestion, with recovery and utilization of the gases liberated. Usually the sludge is digested in two-story sedimentation tanks and the gases collected through gas vents. Separate sludge digestion is also used. The gases are largely utilized to furnish power to operate the disposal plant and to heat the digestion tanks so as to maintain a constant temperature and speed up the digestion process.

An interesting type of tank, developed by Dr. Ing. Prüss, has been proposed for the sewage disposal plant of the Dagenham Urban District. The sewage enters at the center of the tank and flows to the outside. A wood-lath barrier breaks up eddies and gives the sewage a downward flow. Heavy material is ejected immediately into the sludge well. As the flow extends to the outlet under a constant head, the velocity is reduced and the finer particles are deposited. The floor slopes toward the center and is kept clear by means of wooden scrapers which push the sludge to the sludge well in the center. These scrapers need be operated only for an hour twice daily. The sludge well is designed to be cleared daily but an excess capacity is provided for emergency.

Much interest in the German practice has been manifested by British engineers and there is a growing contention that the adoption of German methods is imminent in Great Britain.

Some Considerations in Regard to the Sludging of Detritus and Sedimentation Tanks

By Arnold Holroyd, B.Sc.

The Surveyor, **77**, 217–19 (February 7, 1930)

Abstracted by C. T. Wright

Detritus tanks are essential to the efficient operation of many modern purification works. The Royal Commission advises two or more detritus tanks of capacity of $^1/_{100}$th dry-weather flow without any reference to shape or optimum velocity. For American sewage, Fuller and McClintock recommend, for the cleanest grit, a velocity of one foot per second in the tanks at all flows with a detention period of about five minutes. Grit received at American works varies between 2 and 20 cu. ft. per million gallons flow, necessitating, therefore, individual design of detritus tanks. Recent developments in American practice seem to favor the Dorr detritor, which removes the detritus by a mechanical scraper. In other American plants suction devices are used to remove the detritus from the tanks. These apparently give a mixture of about 10 per cent of grit and 90 per cent of water. They are almost unknown in England.

Elimination of detritus tanks has been suggested where sedimentation tanks intervene and where the sludge is filter-pressed or is disposed of on draining beds, lagoons or land. A gritty sludge is a decided advantage in sludge pressing, decreasing the time of cake formation by 30 per cent. The majority of sewage purification works in England are equipped with sedimentation tanks as a preliminary process and these are of the horizontal and continuous flow type. This type is well adapted to strong colloidal English sewages, which require some 16 hours' sedimentation, but one disadvantage lies in the difficulty of de-sludging.

A form greatly favored in America is the circular dished-bottom tank with continuous non-radial flow, and fitted with mechanical scrapers. A necessary condition for its successful operation is that the scrapers must be totally immersed in the sludge. Under these conditions sludge with 95 per cent moisture is obtained.

German practice is confined largely to the use of two-story tanks. The sedimentation compartment in these tanks may be classed in the category of horizontal, continuous-flow hopper-bottom tanks. These tanks usually are designed to give two or three hours' detention, and settlement with this period is very complete. Another type is the radial-flow hopper-bottom square or circular tank.

The hopper-bottom radial flow, or Dortmund type of tank used in England, ordinarily is designed to be de-sludged by means of the hydrostatic head of water in the tank. This usually results in a thin sludge rarely denser than 98 per cent moisture against 95 per cent obtained by the use of mechanical scrapers.

Fifteenth Annual Report
Bureau of Sewage Disposal, Schenectady, N. Y.

Year Ending November 30, 1929

BY MORRIS M. COHN

ABSTRACTED BY H. GLADYS SWOPE

The average flow treated by the tanks and filters during the entire year was 8.13 million gallons a day.

The effect of winter liming of solids in the Imhoff tanks was tried. Milk of lime was applied by means of a pipe line extending down through the slots into each sludge hopper. On four occasions 800 lb. of lime were added per tank and once 1050 pounds. Samples of sludge and neutral zone liquor were collected. Analyses indicated a slight increase in pH, and an increase in alkalinity was noted in the liquor. No consistently alkaline

pH results were obtained on the sludges, nor was there a reduction of scum depth. A laboratory experiment showed that the addition of lime increased gas production. Treated sludge was stored for two weeks at room temperature, and 1500 cc. of this produced 22,737 cc. of gas whereas the same amount of unlimed sludge produced only 7720 cc. of gas. The pH of treated sludge increased from 7.1 at beginning of test to 7.3 after two weeks, the untreated changing from 6.6 to 6.9. The organic matter in the treated sludge decreased from 72.34 to 66.74 per cent and increased in the untreated from 73.68 to 74.23 per cent during this period.

During the summer of 1929 two gas-collecting domes were designed and installed in one of the tanks. In September, a gas meter was installed which showed a daily production of 200 cu. ft. of gas from two vents. This figure was low due to many possible leaks. It was not considered practicable to install gas collectors for all of the vents.

The sludge on the drying beds was sold to farmers for 25¢ a load.

In an effort to maintain the tanks in a nonodorous condition, the raw sewage was chlorinated at the rate of 4 p. p. m., at such times as humidity and wind conditions were adverse.

Psychoda were controlled during the summer by artificial flooding of the beds. The beds were submerged once in May, four times in June, three times in July and twice each in August and September. All floodings extended over 24-hour periods, shorter periods resulted in a markedly lower killing and a more rapid return of the flies to peak development. It was found best to flood during cool, breezy evenings.

Report of Investigation of Crushed Blast Furnace Slag as a Medium in Sewage Trickling Filters

By Charles C. Hommon

Pamphlet, National Slag Assn., Cleveland, Ohio

Abstracted by H. R. Crohurst

A report of an investigation made to determine the suitability of crushed blast furnace slag for use in trickling filters. It is based upon the performance of all the slag trickling filters that could be located in this country. Thirty-eight such filters were visited together with eleven trickling filters in which aggregates other than slag were being used. The latter filters were inspected primarily for the purpose of making comparisons of the unloading ability of the different aggregates.

A questionnaire, used in connection with the visits to the several plants, served to obtain comparable data from each and these data are presented in tabular form. Physical and chemical characteristics of the respective

filtering materials were obtained from samples collected at the time of the visit to the various plants and analyzed in the laboratories of the National Slag Association.

The results of the field investigation are discussed under the headings of: durability, gradation of material, surface texture of material, clogging, size of material, cleanliness of material, cementation, shape of material and filter flies. The analytical data are presented in tabular form.

From the field investigation and the results of the laboratory data the author believes the following conclusions may be justifiably drawn. (1) The field investigation, in conjunction with sodium sulphate tests on samples collected from existing beds, show that crushed blast furnace slag is a durable material when employed as a sewage filtering medium. (2) In a few filters, portions of the surface material had been affected by (*a*) flaking, (*b*) splitting and (*c*) true disintegration or crumbling. (3) With the exception of one slag bed and one stone bed, this effect was not of sufficient magnitude to alter materially the size of the aggregate or affect operation of the filters. This conclusion is based on the fact that few pieces of slag were found to have failed by true disintegration, and that the flaking resulted in only a negligible quantity of fine material. (4) When exposed to air and sewage, individual pieces of slag containing much metallic iron may ultimately disintegrate, due presumably to the rusting and consequent expansion of the iron. (5) Blast furnace slag as commonly used for sewage filters does not contain a sufficient amount of metallic iron to be objectionable. (6) Improper sizing and gradation were found in all types of filtering material. Absolute adherence to correct size limitations will prevent such a condition. (7) The efficient equipment now employed in preparing air-cooled slag is adequate to crush and screen the material so that it will meet any reasonable specifications. (8) There was no evidence to indicate that crushed slag in the sizes now commonly specified for sewage filters will cement or consolidate. (9) In the few instances where consolidation had occurred, it had been caused by excessive accumulations of fine material in localized areas, due to improper handling of the filtering material at the time of constructing the filters. (10) There is no greater amount of organic deposits retained in slag filters than in those filled with other types of material. (11) The rough texture of blast furnace slag does not prevent the periodic unloading of filters. (12) Laboratory tests in conjunction with the field survey show that the suitability of a slag filtering material cannot be determined by any of the following factors: absorption, specific gravity, weight per cubic foot, loss by abrasion or chemical composition. It is also believed that hardness, toughness and cementing value have no bearing. (13) Slag filters effect a very satisfactory stabilization of the organic compounds in sewage. (14) It does not appear that the type of filtering material has any direct bearing upon the development of the filter-moth fly. (15) The

field investigation indicated that sewage trickling filters (regardless of type of filtering material) would be benefited appreciably by controlling the amount of organic deposits retained in the filter. This can be accomplished by (*a*) periodic resting and drying, (*b*) flooding, or (*c*) chlorination. (16) The information secured through this investigation indicates that crushed blast furnace slag is a suitable and desirable aggregate for use in sewage filters.

The report ends by outlining the factors to be considered in drawing up specifications for slag filtering material and presents suggested specifications for blast furnace slag when used as the medium in sewage trickling filters.—*Courtesy U. S. Public Health Service Abstracts.*

Biological Purification of Creamery Wastes

By Max Levine

Industrial and Engineering Chemistry, **21**, 12 (December, 1929)

Abstracted by Frank Raab

Large septic tanks with six days' capacity were at one time installed in creameries. None proved satisfactory. Domestic sewages rarely require a consumed oxygen demand in excess of 90 p. p. m. The ammonia nitrogen is usually less than 30 p. p. m. Creamery wastes consume from 600 to 1600 p. p. m. of oxygen. The ammonia nitrogen runs from 40 to 140 p. p. m. For sewage the ratio of oxygen consumed to nitrogen is two or three to one; for creamery wastes it is 10 to 1. The decomposition of milk sugar under anaerobic conditions, such as exist in Imhoff tanks, results in high acidities which interfere seriously with septic tank action. Acid coagulating substances, such as casein, are precipitated out and accumulate at the bottom of the tanks. Digestion of casein and gelatin by proteolytic bacteria is materially inhibited by high acidity and completely stopped at a pH of 5.0 to 5.5. Experiments showed that a certain type of trickling filter oxidized lactose rapidly.—*Courtesy U. S. Public Health Service Abstracts.*

Current Status of Methods in Milk Waste Treatment

By A. E. Kimberly

Municipal Sanitation, **I**, 2, Feb., 1930

Abstracted by Kathleen B. Meagher

In 1925 Ohio inaugurated a policy whereby every industry responsible for stream pollution should provide for the disposal of its wastes. At this time a milk industry waste disposal committee was created to study

the disposal problems peculiar to this industry. A study of data compiled in the last seven years revealed that the processing of milk by-products on a commercial scale is a more effective disposal program than the return of skim milk and buttermilk to the producer.

The factors affecting disposal are the conditions at each factory, with respect to permissible loading of the receiving stream on a dry-weather flow basis, and to the concentration of the waste, which is dependent upon the factory processes employed. Since intake losses vary at each factory, investigations are necessary in each case to secure basic design data.

Ordinarily, fresh milk waste is dilute skim milk averaging 1.5 to 2.0 per cent concentration, with a pH of 6.4 to 6.8. At creameries from 10 to 13 per cent of the buttermilk reaches the drains, introducing precipitated casein and whey, both of which increase the oxygen demand. The separation of the buttermilk curd is prerequesite to the biological oxidation of wastes from creameries. The dilution requirements of raw milk wastes in this country range from 35 or 45 to 1, but under certain conditions a stream flow-waste volume ratio of 100 to 1 may be necessary. Where insufficient dilution for aerobic decomposition of lactose to lactic acid prevails, precipitation of casein and formation of sludge banks result. Anaerobic storage of milk wastes is detrimental to subsequent oxidation. Under normal conditions pan water, ranging in volume from 200 to 300 g. p. m., is sufficiently low in organic matter to permit its use as a diluent, and does not require treatment. At a small expense modern factories can separate the pan and cooling water from the milk wastes incident to cleaning down.

Since stream loading is determined by the pounds of milk solids escaping daily, and since this loss is skim milk averaging 9.0 per cent milk solids, the resulting waste assumed as 1.5 per cent skim milk will contain about 1350 p. p. m. milk solids. Milk solids comprise the total residue on evaporation minus mineral solids. Assuming that the 5-day B. O. D.:milk solids ratio is 1.1 to 1, the 5-day B. O. D. of 1.5 per cent skim milk as waste is 1.1×1350 or 1485 parts per million. From these data can be calculated the dilution necessary to maintain the desired quantity of residual oxygen in the receiving stream.

Direct treatment of milk waste on trickling filters is successful if the concentration does not exceed 800 p. p. m. 5-day biochemical oxygen demand. Stable effluents cannot be obtained beyond this concentration. To control the B. O. D. of the waste, measurements of the rate of flow of waste and cooling waters are made, forming a basis for dilution to the desired concentration. Considerable sediment sloughs off trickling filters and under certain conditions it may be desirable to include a small secondary settling tank with a capacity of about 1 hour.

Four full-scale treatment plants designed for a rate of flow of 1.0 m. g. d. were built to handle wastes ranging from 25,000 to 75,000 pounds per day. The waste was applied without preliminary treatment to trickling filters 10 ft. deep constructed of crushed limestone or slag from $1^1/_2$ to $2^3/_4$ inches in size. At a cost of $4500 a plant was built at Bluffton, Ohio, to handle the waste from the Page Dairy Company. The waste of 40,000 pounds at this factory, with an average flow of 6000 gallons per day, flows by gravity to a sump from which it is elevated by a float-switch controlled centrifugal pump to a storage tank of 6400 gallons' capacity. By gravity it then flows to a stone trickling filter 348.5 sq. ft. in area and 10 ft. deep. Tipping troughs effect distribution onto wooden diverging boards. The filtering material is confined by timber bin construction supported by steel I-beams and channels with 2 × 4 cypress spacers between the horizontally placed timber. The filter floor is concrete with drainage leading to an effluent sump.

A similar plant was built for the Golden Star Dairy Company near East Liverpool at a cost of $3000.

A plant is now being designed to handle factory waste amounting to 50,000 pounds per day. It is based on the number of cubic feet of filtering material per pound of milk solids to be oxidized. The ratio between these is tentatively taken at 80 cubic feet per pound.

The Treatment of Dairy Wastes

BY E. W. STEEL AND P. J. A. ZELLER

Bulletin Issued by Texas A. & M. College, Fourth Series, Vol. I, No. 5 (May 1, 1930)

ABSTRACTED BY KATHLEEN B. MEAGHER

In recognition of the increasing problem of milk waste treatment in Texas, an investigation of the lath filter and chemical methods of treatment was undertaken. On the basis of the B. O. D. of the wastes collected, about 750 p. p. m., it was decided to use 1 per cent solutions of skim milk and whole milk in the filter experiments and 0.5, 1.0 and 2.0 per cent solutions for chemical experiments.

Varying amounts of sulphuric acid, ferrous sulphate, ferric chloride and alum were used in the above dilutions of whole milk with the following results:

1. Chemical treatment reduced the B. O. D. by 80 per cent, producing an effluent stable enough to be discharged into streams or upon land without nuisance.
2. Sulphuric acid proved to be the most effective precipitant of casein

and produced a sludge lighter and less bulky than that produced by the other chemicals.

3. Difficulties were encountered in chemical treatment when using waters of varying alkalinity and wastes of different concentrations. Such circumstances necessitated more chemical and more skilled operation.

4. Digestion of sludge and scum was found to be impracticable; drying on porous beds was very slow.

5. Sludge from the sulphuric acid treatment was fed to hogs and chickens. This was considered the best method of disposal but would not be possible if any of the other chemicals were used.

Waste used in the lath filter experiments varied from fresh to 24 hours old. Where it included floor washings a grit chamber was used. The filter was operated at various rates for 24 hours each day. It was found that operating for a period of only 10 hours per day had little effect in allowing higher rates of dosage. The filter was 2 ft. sq. with a wood framework open on all sides. The filtering medium, 5 ft. deep with 5 tiers 1 ft. deep, consisted of laths placed $1^1/_4$ in. apart at right angles to those of the layer above. Four-inch gaps between the tiers facilitated sample collection at each foot. Dosing apparatus consisted of a tipping bucket which discharged into a perforated wood tray, from which the waste dripped onto the laths.

Each kind of waste was applied at a given rate for one week and tests were made of the waste after passing through three feet of the bed and of the effluent. At three-feet depth the waste had become alkaline, a considerable portion of the oxygen demand had been satisfied, and the reduction in oxygen consumed was 60 per cent. The efficiency of the bed was determined by the reduction in B. O. D., and ammonia nitrogen, and the formation of nitrites and nitrates. A trickling filter 5 ft. deep operated at a rate of 1.5 m. g. d. would reduce the B. O D. 80 to 90 per cent and produce a well-nitrified effluent suitable for disposition on land or in streams.

It was found that the lath filter method of treatment of dairy wastes was more effective than the chemical method for the following reasons:

1. No preliminary treatment, except grit removal, was needed.
2. Sludge and scum disposal is not a problem.
3. A better effluent is obtained.
4. Slight treatment can be given to prepare the waste for discharge into city sewers.
5. A filter is more adaptable to fluctuations in the strength of the waste than is the chemical method.
6. Skilled operation is not required.
7. Operating cost is lower.

The River Pollution Problem

The Surveyor, **77**, 309–10 (Feb. 28, 1930)

Abstracted by J. K. Hoskins

The British Ministry of Agriculture and Fisheries discusses this problem from the standpoint of activities of that Bureau covering the years 1925–1928.

Pollutional conditions of British streams have not improved since the war and the existence of fisheries is seriously threatened. The problem and its control is primarily an economic one and while redress under existing law is possible of attainment such procedures are expensive and not wholly effective, especially in the case of fisheries of public or quasi-public character. Coöperation with offending agencies in reducing pollution without recourse to legal action has been successful in many instances.

The Ministry has no authority to take direct legal action for the prevention of pollution, such power being vested in fishery boards or individuals who have first obtained a certificate from the Minister that they have a material interest in the waters alleged to be affected. This failure to intervene has resulted, previously, in criticism of the Ministry, now practically used.

Studies of the effect of road surfacing preparations on the fish life in waters receiving such drainage are in progress and requests have been made to publish lists of road dressings found to be non-toxic to fish. Such requests have been consistently refused in order not to appear to give a guarantee or commendation of trade products. Confidential information is supplied, however, for any particular material on request of a prospective user.

Attention has also been given to the proper disposal of sugar beet factory wastes. Increase in the rates of filtration in biological filters, use of yeast or molds as an aid to breaking down of sugary matters and encouragement of the use of the constant diffusion process, in which no effluent is discharged, are examples of such activity.

Classification of rivers, intensive surveys of streams, collection and tabulation of evidence of pollution and enlistment of industry and public health authorities in control of stream pollution are other functions of the Ministry.

The German Chemical Society, Water Chemistry Group

Technisches Gemeindeblatt, **33**, 5 (January 5, 1930)

ABSTRACTED BY G. P. EDWARDS

Sixty-one German chemists and the Chief Chemist of the Rotterdam water works met in the lecture room of the Prussian Landesanstalt für Wasser-, Boden-, und Lufthygiene, November 25, 1929. After the welcome by Dr. Beninde, President of the Landesanstalt and Dr. Thiessing, Chairman of the Standard Methods Committee, progress reports of the three main sections were given by City Councillor Olszewski of Dresden for the Potable Water Section, Dr. Splittgerber of Wolfen for the Industrial Water Section, and Dr. Nolte of Madgeburg for the Sewage Section. The I. G. Dye Industry Company of Bitterfeld especially deserves credit for editing the preliminary report for the Potable Water Section. In addition to these three sections, a fourth one was organized for mineral waters and Dr. L. Fresenius of Wiesbaden was chosen as leader After discussion it was decided to print the individual methods in loose-leaf form when they are ready for publication. This method facilitates the making of necessary changes and additions. A series of leaflets will be published at intervals during 1930.

Motion Pictures of the Work of the Emscher District, Shown at Manchester, England

Reprinted from *The Surveyor*, **57**, 344 (March 7, 1930)

The lecture hall of the Manchester Technological College was crowded with sewage works managers, engineers and chemists when the cinematograph film prepared by Dr. Prüss, of the Emschergenossenschaft, was shown on the 26th ult. The film had previously been seen by the party of English sewage works managers who toured Holland and Germany last autumn, but this was only the second occasion on which an opportunity has been afforded to others in this country interested in sewage purification to see something of the work of the Emscher Board.

The film opened with a vivid picture of the effect of sewage discharges on a clean stream. A turbid discharge of crude sewage was shown entering a small beck, where it contrasted sharply with the pure stream water. The development of sewage fungi was demonstrated, and remarkably good pictures of the waving fronds of *Sphaerotilus* and *Beggiatoa* were given.

A diagram explaining the different stages in biological self-purification of streams preceded a pictorial account of a polluted stream's progress from conditions of fermentation to a state of purity. As the water recovered from the fouling caused by the sewage discharges, and the dissolved oxygen content gradually increased, vegetation developed and self-purification began. Finally, came the clear-water zone, in which fish were seen swimming among the increased stream-bed vegetation.

The next section of the film was concerned with the plant used in sewage purification. Modern developments in German practice were seen—chiefly in connection with the different types of sedimentation tanks. An unusual apparatus was employed in one instance for applying sewage to land. This consisted of a revolving hydrant, which discharged a strong stream of sewage into the air, where it was somewhat diffused before falling to the ground.

Mechanical and biological treatments of sewage were contrasted and the greater purification obtained by the latter compared with the clarification yielded by the former process was emphasized.

Probably the most interesting—certainly the most spectacular—portion of the film was that which began with the microscopic examination of slime from a portion of filter medium. The taking of the sample was shown and then the film gave a view of the sample as seen through the microscope. There were protozoa, algae and various filamentous growths, all in active condition. The clarity of the photography was most remarkable, and it was possible to see in subsequent samples the sulphur granules in *Beggiatoa*, and to observe the action of the cilia of *Vorticella* and *Carchesium*. Photographs of the microscopic life of fresh water completed the series, and in these diatoms and desmids were seen, together with various water fleas and similar organisms.

Reverting once again to the mechanical aspect of sewage purification, pictures were shown of the ordinary Imhoff tank and the Prüss tank working side by side. Then came views of the sludge-drying areas, where fresh sludge was being run on to the top of sludge which had dried in the beds. The sludge seemed to have quite a low water content as it was being pumped to the beds. The removal by spading and the tipping of the sludge were also shown, and views were given of the sludge-digestion tanks where a workman was seen lighting the gas produced.

The latter part of the film was devoted to the treatment of coal-washing waters and the recovery of phenol and benzol from gas liquors. The removal of sludge after the settlement of coal-washing water was carried out by means of a travelling grab-crane. A diagram explained graphically the method of phenol and benzol recovery.

The film concluded with views of the river clarification plant and the river bed improvements carried out by the Emschergenossenschaft

Pumping stations had been erected to prevent flooding, and the river courses had been canalized and concreted. The view held by the Emscher Board is that the question of rivers pollution prevention should be considered along with river flow regulation, and so this part of the film was interesting as an indication of the practical application of that theory.

At the conclusion of the film exhibition, Dr. Ardern invited questions on the points raised. A member of the audience asked whether the Germans adopted mechanical means for stirring up the sludge during digestion. Dr. Ardern replied that Dr. Prüss said there was a decided advantage to be derived from such mechanical stirring, but, on the other hand, Mr. O'Shaughnessy, whom Dr. Ardern considered the greatest authority on sludge digestion in this country, had expressed himself emphatically against it.

Another member of the audience raised the question of the value of gas produced by digestion. Dr. Ardern said, in reply, that the calorific value of the gas produced was at least 33$^1/_3$ per cent above that of the town's supply. Probably the best value would be obtained from the gas by using it for power purposes on the works. He mentioned that the Germans recommended a temperature of 80° F. for sludge digestion, but the Americans were suggesting that the temperature should be 100° F. In the latter case, much gas would have to be used in obtaining the necessary heat, but it was stated that digestion could then be obtained in eight days. At Birmingham, where the digestion tanks were not heated, complete digestion took three to five months. With the German method digestion would take thirty days.

On the proposition of Mr. A. J. Martin, seconded by Mr. H. Stowell, a vote of thanks was passed to Dr. Ardern for his enterprise in obtaining the film and for the valuable explanatory remarks made by him.

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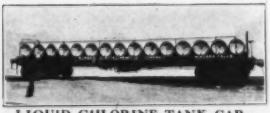

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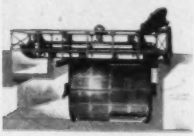

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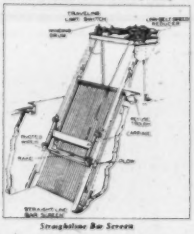

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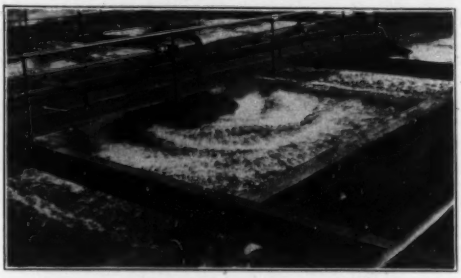

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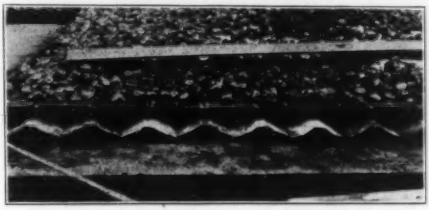

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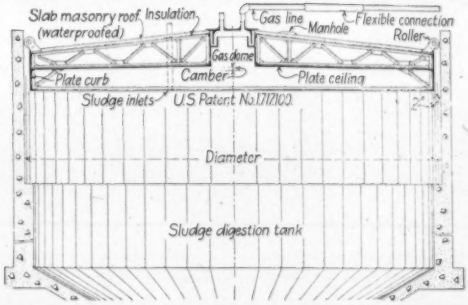

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